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GEOLOGY

·BY·PROF·
J·W·GREGORY

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GEOLOGY

Appleton's Scientific Primers
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BY

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WITH NUMEROUS DIAGRAMS
AND ILLUSTRATIONS

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PREFACE

In accordance with the object of this series of Primers, I have endeavoured, in this short introduction to Geology, to explain some important geological principles which are often omitted from works of this size, owing to the difficulty of presenting these subjects in so short a space and in simple language. I have been encouraged in this course by the rapid spread of scientific knowledge and interest during recent years. It seems now possible to introduce into elementary text-books questions that formerly were necessarily omitted. More space is given to the materials of the earth than to the geographical processes that affect them; for though physical geology is one of the most popular branches of the science, the study of the rocks of the earth's crust is the essential basis of geology. I hope that the sketch of this subject will be found sufficiently popular to be intelligible to the general reader and at the same time useful to elementary students. Those who have no previous knowledge of chemistry would do well to read Sir W. Tilden's primer in this series in order to understand the chemical processes concerned in the formation of rocks.

I am indebted to Mr. J. W. Reoch for the loan of the photographs of Figs. 11, 12, 16, 26, and 27.

J. W. G.

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Map of the World in Upper Carboniferous Era.

GEOLOGY

INTRODUCTION

Geology is the science which investigates the substance, structure, and history of the earth. The materials of which the earth is made supply the records for its history; but these records, enduring and impartial as they may be, are not always easy to read, and it is the duty of the geologist to decipher them by the light of processes which can be seen in operation at the present time.

The chief material studied by the geologist is furnished by the rocks composing the crust of the earth, and their investigation requires a knowledge of several branches of science. Thus rocks consist of minerals, which must be studied with the help of physics and chemistry; and they exhibit structures whose origin can only be explained by the physical geographer, as he watches the formation of similar rocks to-day. Many rocks contain the remains of animals and plants, and their nature must be determined by the aid of zoology and botany. Other rocks have been formed deep beneath the surface, far deeper than man can go, but we are beginning to learn more of the nature of the earth's hidden substance from the study of earthquakes and the investigation of radium. Occasionally lumps of mineral, found upon the earth, have fallen on to it from the sky; the astronomer must explain their origin, while learning from their mineral composition something about those other worlds which are the object of his special research.

Hence, geology is largely dependent on other sciences for its advance: it depends on the help of chemist, physicist, geographer, zoologist, botanist, and astronomer. The geologist applies their several discoveries to the elucidation of his own problem—the examination of the substance, structure, and history of the earth. His work is therefore varied, and the mastery of any one branch of geology requires a knowledge of the various sciences connected with that branch. Hence geologists usually find themselves obliged to confine their activity to some one branch of geology; but their efforts in a special direction will only yield the fullest results when based upon an understanding of geology as a whole.

An elementary statement of the main conclusions of geology may be understood without reference to the methods by which they have been gained, though it will always be necessary to learn the technical terms used for new ideas and specific materials.

Though geological research usually requires some previous training in other branches of science, yet valuable original work may be done by those who, without any elaborate equipment or special knowledge, will carefully observe the rocks, collect the fossils, or ponder over the structure of the country around them.

PART I

CHAPTER I

THE EARLY HISTORY OF THE EARTH

"IN the beginning the earth was without form, and void, and darkness was on the face of the deep."

The story of the earth, from its original formless state and primeval darkness till the beginning of written history, is the subject-matter of geology. The story is imperishable, for it is inscribed on the rocks of the earth's crust, and their evidence is less liable to error than those human records which are subject to the distortions of prejudice and misapprehension.

Before the records of rocks can be read their language must be learnt. The particles of the earth's crust are the letters of the story, and they all help to tell what was happening on the earth at the time they reached their present resting-place. Some of the materials are easily examined and their interpretation is clear. Gravel-pits, for instance, occur in the neighbourhood of most large towns, and the pebbles of the gravel tell clearly of past changes in the earth, for they were once part of rock masses now partly or wholly destroyed.

Again, the materials of the earth's crust are exposed along the cliffs of the sea-shore, on river banks, and as ribs of hard rock jutting out from the hill-side. These rocks may also contain petrified shells, which will indicate when the rocks were laid down, and whether in fresh water or beneath the sea.

Some of the materials of the earth's crust, however, are deeply buried, and only accessible in mines, wells, or bore-holes. Others are beyond our direct reach, and must be investigated by indirect methods; but such evidence as they afford, though more difficult to obtain, may be as clear and instructive as that of material which can be actually obtained and handled.

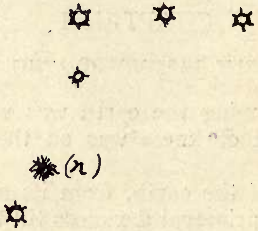

Fig. 1.

The Position of the Nebula in the Sword of Orion. The three small stars represent Orion's Belt: the nebula (n) surrounds the middle star (θ) in the Sword. The stars are arranged as they would appear in Britain at 9 p.m. in the latter part of January.

The state of the earth was originally very different from its present condition; for, though it may have contained much the same amount of material as it does now, it occupied a far larger space, and was spread out in a loose cloud of scattered bodies. On a clear starlight night look at the three stars known as Orion's Belt, and below them, if the observer be in the northern hemisphere, will be seen a curved line of three stars — the Sword of Orion (Fig. 1). Examine the middle star closely, if possible through a telescope or pair of opera glasses; but even with the naked eye that star will appear to be more misty and to have less definite borders than its neighbours. It is a nebula, and its condition, as revealed by a powerful telescope, is illustrated by Fig. 2, while another nebula (in the constellation of the Hunting Dogs), which has a spiral structure, is illustrated by Fig. 3.

Fig. 2.
The Great Nebula in Orion.
(*From a photograph taken by the Yerkes Observatory.*)

The earth was once a hot nebula, but the condition of its material then is uncertain.

Opinions differ as to whether it consisted of a vast cloud of incandescent gas, which condensed as it cooled, or whether its earliest condition was a swarm of metallic masses, composed mainly of iron and nickel, which slowly united into a compact whole. This union would have been accompanied by so great an increase in temperature that the separate iron bodies would have been fused into one mass.

The arguments for and against a gaseous, or a solid swarm-like beginning of the earth are largely derived from astronomy; and the question mainly concerns the geologist from its bearing on the geographical conditions at the dawn of geological history. For if the earth had been once composed of white-hot gas, its first known climate should have been much hotter than that of the present time, and the temperature should have become slowly cooler. If, on the contrary, the earth began as a swarm of solid bodies, it need never, as a whole, have been much hotter than it is now.

Geology shows that the earliest known climate was very similar to that of to-day. The raindrops were of the same size, and the wind was of the same force, while, instead of the earth being warmer than now, icebergs floated nearer the tropics in the primeval than in the existing seas.

Geological records give no certain evidence of any period in the earth's past, when the climate of the whole earth was much hotter than it is to-day, nor do they afford any indication of a time when wind, rain, tide, and other geographical forces were of much greater power than they are now.

The distribution of physical activity on the earth has, however, often been different, as may be seen when we study volcanic rocks. The only active volcanoes in Europe are Vesuvius and Etna on the Continent, as well as the volcanic islands near Sicily, those in the Grecian Archipelago, and the two northern islands of Iceland and Jan Mayen. Going to earlier times, we find records of probable volcanic eruptions in central France as late as the fifth century A.D.; extinct volcanoes are to be found in nearly all European countries, and not only were volcanoes once active in many places where they are now ex-

Fig. 3.

The Spiral Nebula in the Constellation of the Hunting Dogs.
(*From a photograph by the Yerkes Observatory.*)

The evidence of the spectroscope indicates that the material of this nebula is solid.

tinct, but at certain earlier periods volcanic action was far more widespread than it has been during the experience of man.

Again, there are no glaciers at present in the British Isles; but the mountains of Wales, Scotland, and the north of England were once snow covered all the year round, and rivers of ice flowed down the mountain slopes and covered parts of the British lowlands.

It is clear, therefore, that there have been great changes in the geography of the world in past times; and the present condition of the earth's surface is the result of an unceasing struggle between the forces of waste and the forces of repair. We have only to look attentively at the district in which we live, to see that these forces are still at work.

In the city we can observe the decay—the often deplorably rapid decay—of stones used for building; and it is rare in a churchyard to find an intelligible inscription on a tombstone more than a century or two old, unless it has been recut. In the country we notice the crumbling of rocks before the weather, the deepening of lanes and roads by the wear of traffic and the wash of rain. Along the coast we observe the cutting back of cliffs by the attack of the sea. How unceasing and rapid is the waste of the land may be judged by looking at an ordinary lowland river; the water is usually of a brownish colour, owing to the quantity of floating mud it contains—mud derived from the wearing away of the land. The amount of material thus removed by rivers is enormous. Every year the Thames carries to the sea over 500,000 tons of mineral matter. The load of material is dropped by the river on its bed or at its mouth as a delta, or spread over the floor of a lake or of the sea.

Thus land is being formed at one place with the materials derived from the destruction of land at another place; and the most elementary problems in geology are concerned with these processes, which are still moulding the surface of the earth; but to understand these processes of rock destruction and rock formation, it is necessary first to consider the nature of the materials of which the earth is made.

PART II

THE MATERIALS OF WHICH THE EARTH IS MADE

In whichever manner it may have originated, the earth as a whole may be regarded as a ball, consisting of a central core, covered by three successive skins or layers, which form the main field of geological research.

The vast, inaccessible, central mass, which constitutes by far the largest part of our earth, is hidden from our observation and shielded from our experiments.

Where sense fails us mind alone can penetrate, and our knowledge concerning the central core of the earth is almost entirely a matter of inference and analogy.

Two words have been employed as names for this central core; it has been called the centrosphere on account of its central position, and the barysphere on account of its weight. *Barus* is the Greek word for " heavy," and when we use the term " barysphere " we are affirming the one definite conclusion that has been arrived at as to the nature of the earth's central mass, and that is its exceptional weight. The materials composing the core of the earth are more than twice as heavy as the materials composing the superincumbent outer layers.

The term "barysphere" is therefore appropriate to the unexplored core of our earth.

The barysphere is surrounded by the lithosphere (Greek *lithos*, a rock), the rocky crust of the earth. Resting upon the lithosphere is the hydrosphere, which includes all the waters on or in the earth's surface; and the outermost layer is the atmosphere, the gaseous envelope which completely surrounds the earth; thus recalling the four elements of the ancients—earth, air, fire, and water.

The chief materials with which the geologist has to do are the rocks of the outer layers of the lithosphere.

The term "rock" appears to be derived from the same root as the word "crag," and to mean a firm, stony material. It is used in that sense in current English, but by a widely accepted convention some geologists, for the sake of convenience, apply it to all the materials of the earth's crust, and thus regard loose beds of sand and soil, ice, and even water, as rock. This use of the word ignores the essential idea of the term, as expressed in the comparison "firm as a rock." It will therefore be clearer to use the term "rock" in its primitive and ordinary sense, taking the word "crust" to describe the whole covering of the barysphere, which we roughly divide according to its solid, liquid, or gaseous components into lithosphere, hydrosphere, and atmosphere.

CHAPTER II

THE MATERIALS OF THE EARTH'S CRUST

THE materials of the lithosphere, the solid layer of the earth's crust, belong to two main divisions, and are classed as primary and secondary rocks. Primary rocks are those which have been formed by direct consolidation from molten material. Secondary rocks are those which have been formed by the destruction of the primary rocks and the redeposition of their material.

The primary and secondary classes of rocks may be separated by several well-marked characters. Primary rocks are composed mainly of crystalline materials, or of a natural glass; secondary rocks are mostly formed of fragmentary grains, and they are therefore said to be "clastic" (Greek *klastos*, broken in pieces).

A second important distinction is that the primary rocks frequently occur in large masses, which are often uniform in character for a great thickness; whereas the secondary rocks are formed of a succession of layers or "strata" that have been deposited one over the other, and though these layers may be uniform in character over wide sheets, they usually occur in layers which are thin in comparison to their extent.

The primary rocks not being formed in layers, are said to be "unstratified," while the secondary rocks are termed "stratified."

Some of the secondary rocks are not composed of fragments of primary rocks, but they are formed from the skeletons and shells of the animals and plants which lived while the rock was being formed. The remains of animals and plants buried in the earth's crust are known as fossils, and they may occur either as a small percentage of a rock or as the main bulk of it. Skeletons and shells consist of material which has been derived from the primary rocks; so fossils are regarded as secondary rock constituents. Hence, the presence or absence of fossils is a further distinction between the primary and secondary rocks. For as primary rocks were formed under conditions too hot and usually too deeply buried beneath the earth's surface for the existence of animals or plants, they contain no fossils; whereas most secondary rocks contain fossil remains of the organisms living at the place where the rock was being formed, or which have been washed into it from some older rock. Primary rocks are, therefore, unfossiliferous, and secondary rocks are usually fossiliferous.

Primary rocks, having been formed under the influence of intense heat, are described as igneous rocks; while as a large proportion of the secondary rocks have been laid down under water, they are called aqueous rocks; and the rest, which were formed on land, are called æolian or subaerial rocks.

These differences are summarised in the following statement—

Primary rocks are Igneous, Unstratified, Crystalline or Glassy, Unfossiliferous.

Secondary rocks are Aqueous or Subaerial, Stratified, Fragmentary, Fossiliferous.

CHAPTER III

THE PRIMARY OR IGNEOUS ROCKS AND THE MINERALS OF WHICH THEY ARE COMPOSED

THE primary or igneous rocks are divided into two main series—those that consolidated at a great depth beneath the surface, and those that consolidated at or near the surface. The deep-seated igneous rocks are called "plutonic," after Pluto, the god of the infernal regions; the superficial igneous rocks are called the "volcanic," after Vulcan, who had his workshop near the earth's surface. Intermediate between these two groups are the rocks that have solidified beneath but near the surface, in fissures or pipes filled by molten material that has been forced into them from below.

The factor that determines whether liquid rock material forms a plutonic or a volcanic rock is the pressure at which it solidifies. If a mass of molten rock be cooled quickly and at slight pressure, it solidifies as a glass; but if it cool slowly and under heavy pressure, it solidifies as a stony mass. This fact is exemplified in the preparation of the glass known as Chance's artificial stone. Basalt is melted and poured into moulds, and when it cools quickly, it solidifies as a glass; but if it cool slowly, it forms into a stony mass composed of a mixture of glassy and crystalline materials. The dull, earthy-looking basalt is composed of a mixture of minerals, which are not glassy but crystalline, though the crystals may be too small to distinguish by the unaided eye; but if examined by a powerful lens, or still more clearly if a thin slice of the rock be examined with the aid of the microscope, it is seen to be composed of a mixture of materials, of which most, or perhaps all, are crystalline.

The essential difference between a crystalline and a glassy substance is in their minute internal structure. In a glass the particles are arranged irregularly, whereas in a crystalline substance the particles are arranged regularly, so that a given number of particles occupies less space in the crystalline than in the glassy condition. Hence, if a molten material be solidified under such heavy pressure that it is compressed into the smallest possible space, it must solidify as a crystal and not as a glass.

Fig. 4.

Three Sections of Rocks.

a. A Granite. The large angular crystals are the felspar; the black is the mica; the rest is mainly quartz and felspar.

b. A Liparite. The large clear crystals are the corroded felspars: the lath-shaped crystals the mica: the rest is the glassy base.

c. A Grit. A sedimentary rock mainly of grains of quartz (the clear grains) and felspar (the grains with the crowded dots).

This fact may be illustrated in various ways. Thus a granite is a rock which has cooled under such enormous pressure that all its materials are crystalline; but if a piece of granite be melted and cooled quickly free from pressure, it will solidify as a glass. This granite glass is lighter, bulk for bulk, than the crystalline granite; thus a cubic foot of granite weighs about one hundred and seventy pounds; but a cubic foot of the glass formed by the melting and quick cooling of this granite will weigh only one hundred and fifty pounds. A cubic foot of basalt weighs about one hundred and eighty pounds, and of basalt glass only one hundred and sixty-four pounds.

The presence or absence of glass in a primary rock therefore affords a measure of the depth and pressure under which the rock solidified. A rock consisting wholly of glass must have been formed on the earth's surface, and under slight pressure. A rock formed wholly of crystalline material, on the other hand, has usually consolidated under heavy pressure. Hence plutonic rocks are wholly crystalline, or "holocrystalline." Volcanic rocks may be wholly glassy like obsidian; or they may be composed of a mixture of glassy and crystalline material, and then they are partly crystalline, or "merocrystalline."

The primary rocks of the earth's crust are mostly composed of a comparatively few distinct kinds of crystalline material. Each kind of these crystalline substances is known as a Mineral Species; and an igneous rock is usually a mixture of two, three, or more of these mineral species. The chemical composition of most mineral species is more or less constant; so that by determining the various mineral species present in a rock, and their relative proportions, the total composition of the rock can be determined. The identification of minerals in rocks is most easy in those which are composed of crystals large enough to be recognised by the naked eye, and as this is the case in the plutonic rocks, it is most convenient to study them first.

The mineral species of which rocks are composed belong to the following groups—

1. *Quartz.* — This mineral — known as rock-crystal when found in the clear transparent crystals used for "pebble" glasses—consists of the element silicon combined with the gas oxygen, forming the compound silica (SiO_2). Quartz sometimes occurs as six-sided crystals, composed typically of a six-sided prism with a six-sided pyramid at each end; but it is usually found as irregular grains. It is so hard that it cannot be scratched by a knife, it has a glassy or milky-white appearance, and it is not dissolved by water or most acids.

2. *Felspar.*—The felspars are a group of mineral species which agree in many respects in form, properties, and composition. They all contain silica (SiO_2) and alumina (Al_2O_3); some of them contain in addition the alkalies potash (K_2O) or soda (Na_2O), and others contain the earth, lime (CaO), or mixtures of lime and soda. The felspars are of two kinds: the basic[1] felspars, which contain more lime than alkali; and the acid[1] felspars, those containing more alkali than lime, and a higher percentage of silica than the basic felspars.

3. *Felspathoids.*—a group of mineral species which may sometimes replace the felspars in igneous rocks; the chief species are leucite, sodalite, and nepheline.

4. *Micas*—a group of mineral species, which

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[1] For the definition of acid and base, see Sir W. Tilden's primer on Chemistry, p. 91. A base is a material the whole of which will combine with an acid.

all crystallise in flat plates or scales, and have the quality of breaking into thin flat elastic scales or "cleavage flakes." Ordinary white mica, which is used for lamp shades, is composed of silica, alumina, and potash; the black and brown micas contain silica, iron, and magnesia, and the presence of the iron makes them heavier and darker in hue than the white micas.

5. *Ferromagnesian Minerals* — a group of mineral species partly formed of iron and magnesium. These two constituents are known as the "femic" constituents, from the combination of the first letters of their chemical symbols, Fe and Mg. The chief of the femic minerals are the amphiboles (*e.g.* hornblende), the pyroxenes (*e.g.* augite), and olivine. The dark colour of many igneous rocks is due to the abundance of the femic minerals. Owing to the iron present these femic minerals are usually dark in colour, and heavier, bulk for bulk, than minerals richer in silica.

6. *Accessory Minerals.*—Many igneous rocks contain small grains and crystals of various oxides of metals, such as magnetite, oxide of iron; also crystals of apatite, phosphate of lime, and of zircon and other minerals.

The leading difference between the members of these six groups of minerals is the varying amount of the "acid" or silica present, in relation to the oxides of the metals and other "basic" constituents. Thus quartz (SiO_2) consists wholly of silica, and there is no basic constituent present; while passing through the other groups, there is a steady increase in the amount of "base" present, till magnetite (Fe_3O_4), a member of the last group, consists wholly of base, and contains none of the acid.

Hence igneous rocks rich in quartz contain more acid than rocks that are without quartz, and are rich in iron and magnesia.

The plutonic rocks are divided into various classes according to their composition; those which contain much quartz—the acid constituent—are the acid rocks, such as granite. From this extreme on the one side, to the ultra-basic group on the other, there is a gradual passage, marked by a decrease in the amount of silica and alkalies, and an increase in the proportion of basic materials, the iron, magnesia, and lime, to the ultra-basic group. The rock series is continuous, but it is divided for convenience into five main classes. The chief rock in each class is as follows—

Rock	*Constituents*
Granite	Quartz, acid felspar, and mica
Syenite	Acid felspar and hornblende
Diorite	Basic ,, ,, ,,
Gabbro	,, ,, ,, altered augite
Peridotite	No felspar; the rock is often mostly composed of olivine

Each of these rocks is composed wholly of crystalline materials, and the minerals are usually so large in grain that they can be recognised by the unaided eye.

These plutonic rocks generally occur in large thick masses, which may be many square miles in area, and are of great and usually unknown thickness. Thus the whole of Dartmoor consists of one great block of granite 200 square miles in area. The rock on the edge of such a mass cools more quickly than that in the middle, and thus the grain of the rock is finer on the margin. Tongues or sheets of granite may project from the mass into the surrounding rocks; these tongues or sheets are known as dykes, and their rocks may be composed either entirely of crystalline material, or of a mixture of crystals and glassy rock material.

Some of the fissures into which these dyke rocks were forced from below may have reached up to the surface, and their material may then have been discharged in volcanic eruptions.

If the plutonic rock be a granite, then the lava which pours over the surface through a volcanic vent will be a rock light in weight, pale in colour, and rich in silica; and as lavas of this type have been discharged abundantly from the volcanoes of the Lipari Isles near Sicily, these lavas are called liparites. If a dyke rock from a gabbro mass reach the surface, the material will flow as a lava which is darker in colour and heavier than the liparite, and it will not contain any quartz; it will be a basalt. Each kind of plutonic rock has its corresponding lava.

The lava	equivalent of a	granite	is a	liparite
,,	,,	syenite	,,	trachyte
,,	,,	diorite	,,	andesite
,,	,,	gabbro	,,	basalt or dolerite
,,	,,	peridotite	,,	limburgite

There are also intermediate varieties of plutonic rocks, each with its corresponding lava.

The various types of plutonic rocks are not separated by sharply defined boundaries; each rock grades into the varieties on either side of it, and there is a continuous series from the most acid to the most basic rocks. Indeed, it is possible that all the rocks in the series may be variations from one rock material, and that the diversity of products from the same source is due to the fact that the different minerals crystallise out of a molten mass in a regular succession.

The basic minerals crystallise before the more acid. The very basic accessory minerals, including the metallic oxides, crystallise first; the ferromagnesian minerals, being less basic, follow; then come the still less basic felspathoids and felspars; and finally the baseless quartz. The sequence of the minerals is, therefore, in the order of decreasing baseness or basicity. As the more basic materials are removed from the molten rock by crystallisation, the molten residue gradually becomes more and more acid. Moreover, as the basic minerals are developed, they tend to collect either on the bottom or on the cooler margins of the solidifying rock mass. Hence by this process, the collection or segregation of the basic material, the mass loses its originally uniform composition, and divides into two parts; one of them may have the composition of a granite, and the other of a gabbro; and they may be discharged at the surface as acid and basic lavas. This gradual separation of the acid and basic constituents is known as differentiation, and by this process different types of igneous rocks are produced from one uniform mass of molten rock.

CHAPTER IV

THE CLASSIFICATION OF THE PRIMARY ROCKS

A CLASSIFICATION of rocks, to be of general usefulness, must express two facts about them: first, the composition of the rock, on which its economic value often depends; and second, the conditions under which the rock solidified, since they determine its structure, appearance, and often its colour. Rocks of very different composition may resemble one another more closely than rocks having identically the same composition. Thus a piece of granite may closely resemble in appearance pieces of the rocks known as diorite or gabbro, as they may each consist of a coarse-grained mixture of a white and of a black or dark-green mineral, and will all look alike though they differ widely in their composition. A granite, on the other hand, may have exactly the same composition as obsidian, although they differ totally in their appearance, for obsidian looks like black bottle glass.

The following table shows the composition of four different rocks—

	Granite, Dublin.	Quartz-felsite, Bohemia.	Rhyolite, Styria.	Obsidian, Mexico.
Silica (SiO_2)	73	74	73	74
Alumina (Al_2O_3)	14	13	14	14.25
Oxides of iron (Fe_2O_3 & FeO)	2.5	2	1.4	1.8
Magnesia and lime (MgO, CaO)	1.9	1.5	1.55	1.4
Alkalies—soda and potash (Na_2O, K_2O)	7.7	7.6	8.1	9

These four rocks, though coming from distant localities, have almost the same composition; but the four rocks are quite different in appearance. The granite is a coarse-grained, grey rock, which can be seen by the naked eye to be composed wholly of quartz, felspar, and mica. The quartz-felsite and the rhyolite are finer grained, and of a darker grey colour than the granite; and it is only by the use of a lens that occasional fragments may be found in them large enough for recognition as distinct mineral species. The last of the four rocks, obsidian, is a black, smooth, shiny glass. Hence one molten rock material may produce several different kinds of rocks; and the difference in the product will be due to the conditions under which it solidified. Granite is the rock formed when acid rock material has cooled very slowly under the pressure of overlaying rocks which are miles in thickness. If the same rock material be forced up a fissure, and thus cools more quickly and under less pressure, it forms a felsite. If the fissure reach the surface of the earth and the molten rock overflow the surface as a lava stream, it forms a rhyolite; and if the surface of the flow is cooled very quickly, it forms a sheet of obsidian. All these four rocks belong, then, chemically to the same group, and are formed of the same rock material or Magma. Whether this magma solidified as a granite which is wholly crystalline, or as obsidian which is entirely composed of glass, depends simply on the conditions under which it solidified.

The igneous rocks may be divided into five groups according to their chemical composition. All the rocks of each of these groups are produced from one kind of molten rock or magma, and the exact kind of rock produced depends mainly on the depth at which their material solidifies. The chemical composition of the typical rock of each of these five groups is shown on the following table—

Rock Group.	Acid.	Sub-acid.	Sub-basic.	Basic.	Ultra-basis.
Rock.	Granite.	Syenite.	Diorite.	Gabbro.	Serpentine.
Silica (SiO_2) . . .	72	60	53	50.8	41.6
Alumina (Al_2O_3) . .	15	16.8	12	17.2	4.2
Oxides of iron (Fe_2O_3 and FeO) . . .	2.2	7	8.7	10.7	13.3
Potash (K_2O) . . .	5.1	6.6	2.2	2.6	
Soda (Na_2O) . . .	2.8	2.4	2.8		—
Lime (CaO) . . .	1.6	4.4	9.7	10.3	1.7
Magnesia (MgO) . .	0.3	2.6	2.1	7.1	34.8
Water (H_2O) . . .	—	—	—	—	5.0
Specific Gravity .	2.66	2.7	2.8	2.82	3.1

This table shows that the chief differences in composition between these five types are as follows: (1) A decrease in the amount of silica as the series is followed from granite to serpentine; (2) a decrease in the amount of the alkalies, potash, and soda; and (3) an increase in the amount of the bases, lime, magnesia, and oxide of iron. As the silica is the acid constituent, and the lime, magnesia, and the iron oxides are the basic constituents in rocks, it follows that the granite is the more acid, and that the gabbro and serpentine are the more basic.

Granite is the type of the group known as the Acid Rocks, and gabbro of the Basic. Between them are two intermediate stages, of which the syenite, being nearer to the granite, is known as the sub-acid, and the diorite, being nearer to the gabbro, is known as the sub-basic. The serpentine, having even less silica and more bases than gabbro, is known as the ultra-basic group.

The influence of the chemical composition of the rock taken in bulk naturally influences the minerals that compose it. In the gabbro there is so little silica that it is all used up in combination with the other constituents, and there is none of it left to crystallise as free silica or quartz. In the granite, on the other hand, the amount of silica is so large that, after the other constituents present have combined with as much silica as they can use, there is an excess left over which solidifies as free quartz. The acid group is, therefore, rich in quartz; a little quartz is present in the sub-acid, and in both these rocks the felspar that is present is an acid felspar, because it contains much silica. In the gabbro, on the other hand, the felspar is a basic felspar, which contains a smaller proportion of silica than the felspar of a granite; and there is usually also present the mineral olivine, which contains a smaller proportion of silica than any of the constituents of granite. Olivine cannot be formed in the magma that produces granite, because the basic constituents of the olivine would combine with some of the extra silica and form a more siliceous, *i.e.* a more acid mineral species than olivine.

Quartz, then, is characteristic of the acid rocks, and olivine of the basic.

Five groups of rocks based upon composition may be arranged as in the table opposite.

In each of these five groups of rocks there is a sub-group, the members of which differ from those of the normal group by containing a much higher percentage of alkalies, usually soda. An igneous rock, very rich in soda and corresponding to the liparite, is known as a keratophyr; the soda-rich rock corresponding to the trachytes is a phonolite; that corresponding to an andesite is a tephrite; and that corresponding to a basalt is a basanite.

Some simple method is required for determining to which group any particular rock belongs. To make a full chemical analysis of a rock is a serious labour, which usually takes a skilled chemist about a week. Hence a chemical classification of rocks would be of little practical value to a geologist in the field, if there were not some simple test by which rocks could be assigned to their respective groups. In the case of a coarse-grained rock like a granite or a gabbro, the group may be determined by identifying the mineral

Group.	Mean Silica percentage.	Characteristic Minerals.	Typical Rocks.		
			Deep-seated.	Volcanic.	Glassy.
Acid . . .	73	Quartz, acid felspar, white mica	Granite	Liparite	Obsidian
Sub-acid .	63	Acid felspar, hornblende	Syenite	Trachyte	Pitchstone
Subbasic .	57	Basic felspar, hornblende	Diorite	Andesite	,,
Basic . .	50	Basic felspar, pyroxene, olivine	Gabbro	Basalt	Tachylyte
Ultra-basic .	45	No felspar; olivine and pyroxene	Peridotite	Limburgite	—

species of which it is composed; but if the rock be very fine-grained, the minerals can only be recognised under the microscope; and even the microscope does not always give conclusive evidence about a volcanic glass.

The chemical group of a fine-grained rock may often be recognised in the field by examining some weathered surface. As the basic rocks are rich in iron, their weathered surfaces are stained a brown rusty colour; whereas an acid rock, owing to its poverty in iron, weathers of a light or grey colour.

A more precise test which can be easily applied depends upon the different weight of the rocks. Quartz is a comparatively light mineral, weighing only 2.6 times as much as an equal volume of water; that is to say, its specific gravity is 2.6. Hornblende and augite, on the other hand, weigh 3.2 times as much as an equal bulk of water; olivine is 3.4 times, and magnetite more than 5 times heavier than an equal bulk of water. Hence, as an acid rock is rich in quartz and contains no olivine or magnetite, it is lighter than a basic rock rich in these constituents. The specific gravity of a rock can be easily determined by weighing a specimen in air, then weighing it suspended by a fine thread in water, and dividing the weight in air by the difference between the weights in air and in water. Thus—

$$\text{Sp. gr.} = \frac{\text{Weight in air}}{\text{Difference between weight in air and weight in water}}$$

Specific gravity affords a test of the amount of silica present in a rock. Thus, according to a table compiled by Dr. Teall—

			Average sp. gr.		*Silica*
23	varieties of	granite	2.65	and contain	71.6%
10	,,	syenite	2.82	,,	63.8%
13	,,	gabbro	2.90	,,	51.5%
5	,,	peridotite	3.26	,,	44.6%

A cubic	foot of	average	granite	weighs	165	lbs.
,,	,,	,,	syenite	,,	175	,,
,,	,,	,,	diorite	,,	177	,,
,,	,,	,,	gabbro	,,	180	,,
,,	,,	,,	peridotite	,,	203	,,

This simple and easily applied test therefore indicates the approximate amount of silica present in a rock, and thus enables it to be referred to its group without the necessity for a chemical analysis.

CHAPTER V

THE SECONDARY OR STRATIFIED ROCKS

The primary materials of the earth's crust consist of an igneous material which has been given off like a slag from the consolidating central core, and then by process of differentiation has divided into two types of slag; the acid type has been aptly called the salic, from the initials for its two chief constituents, silica and alumina; the more basic product is the femic (*see* p. 26). The salic product constitutes the granites, syenites, and liparites—the femic supplies the gabbros, dolerites, and basalts; various mixtures of the two form the intermediate types, such as diorite and andesite.

When these primary rocks are exposed to the action of the rain, wind, and weather, their constituents are gradually decomposed. Perfectly pure water acting at a constant temperature on a slab of fresh granite would have practically no destructive effect. But such are not the conditions met with in nature. Rain water is not pure; it is slightly acid, as it always contains some carbonic acid derived from the air, as well as some oxygen. The rain that falls in cities generally contains sulphuric and hydrochloric acids as well. The temperature, moreover, varies continually; and exposed surfaces of rock expand when heated and contract when cooled; and if the cooling and the resulting contraction be rapid, the rock is torn by cracks. Moreover, different minerals expand at different rates when warmed; and thus a rock like granite, which is composed of three constituents, is rent internally by the unequal expansion of its minerals. The rain water soaks into the cracks, and its acids and oxygen are thus able to act upon the minerals on all sides. The water that soaks into a granite first attacks any dark-coloured mica that may be present, and removes its iron; the carbonic acid decomposes the felspar, and removes in solution its lime, potash, or soda. The rest of the felspar remains as silicate of alumina, or common clay substance, mixed with any excess of silica which is left as quartz. The original quartz in the granite is not appreciably attacked, but it falls out after the destruction of the felspar and mica, and it is washed away by the rain.

In the basic igneous rocks analogous changes happen: the oxygen, owing to the complex process known as rusting, combines with the iron and converts it into an iron oxide or rust; or the carbonic acid may combine with the iron to form a bicarbonate of iron, which is removed in solution The carbonic acid also attacks any minerals containing lime, and forms a bicarbonate of lime which is removed in solution. Slowly the whole rock decays to a clay, stained brown by iron oxide. The fine grains of clay substance are then blown away by the wind as dust, or washed by the rain into streams and carried away as silt.

The destruction of the primary rocks gives rise, then, to the following materials—

Primary Rocks.	Constituent Mineral Species.	Chemical Composition.	Method of Removal.	Deposited as
Granite	Quartz	Silica	Silica in suspension	Sand grains
	Acid felspars	Silicate of alumina	Silicate of alumina in suspension	Clay
		Silicate of potash	Carbonate of potash in solution	
		Silicate of soda	Carbonate of soda in solution	
	White mica	Silicate of alumina Silicate of potash	As flakes of mica in suspension	Mica flakes
	Brown mica (if present)	Silicate of alumina Silicate of magnesia	As flakes of secondary decomposition products	
		Silicate of iron	Iron removed in solution	
Gabbro	Basic felspars	Silicate of alumina	Clay in suspension	Clay
		Silicate of lime Silicate of soda	Secondary silica in suspension	Sand grains
			Bicarbonates of lime and soda in solution	Lime in limestone; soda in salt deposits
	Ferro-magnesian mineral	Silicate of alumina	Clay in suspension	Clay
		Silicate of magnesia Silicate of iron Silicate of lime	Secondary silica in suspension	Sand grains
			Bicarbonates of lime, magnesia, and iron in solution	Limestone, etc.

The new materials are distributed by wind and water, and laid down as stratified deposits. These beds may be cemented and form secondary rocks, which are classified according to material or mode of origin. Most secondary rocks are formed from fragments of primary rocks, laid down as sediments; hence secondary rocks are sometimes called sedimentary rocks, and sometimes they are called clastic rocks, from the Greek word *klastos*, broken.

If these rocks are formed by the agency of the wind, they are called æolian or subaerial rocks; if formed by water, they are called aqueous rocks; the deposits due to ice are described as glacial.

The materials of some secondary rocks are carried in solution by water, and their solution and redeposition are due to chemical or organic and not to mechanical processes. The materials may be extracted from the water, either by the action of some animal or plant which has the power of extracting the material from solution and secreting it as its shell, or skeleton, or stem. These rocks are known as the organically formed rocks. The material may, however, be removed from the water by some chemical process, and such deposits are said to be chemically formed.

The material therefore obtained by the destruction of the primary rocks is redeposited as secondary rocks by three processes, which give rise to three groups of rocks—the sedimentarily, the organically. and the chemically formed.

CHAPTER VI

THE SEDIMENTARY DEPOSITS

THE rocks formed by the mechanical transport and deposition of material derived from the primary rocks are most conveniently classified according to the nature of their chief constituent. There are two main groups of sediments—the arenaceous (from Latin *arena*, a sand grain) and the argillaceous (from Latin *argilla*, clay).

The Arenaceous Series.—The simplest member of the arenaceous series is sand, which consists of small grains of various minerals; the commonest is quartz, as owing to its hardness and durability, its reduction to very fine powder is a very slow process. The sands found in the British Islands are usually composed of siliceous fragments; hence sand is often spoken of as if it were always siliceous. But in many localities the sands are composed of grains of felspars; many sands on the sea-shore consist of carbonate of lime formed by the breaking up of shells or corals. The white sands of the beaches on the Pacific coral islands are composed of grains of corals and shells, and so are calcareous. Sand grains may be rough, sharp, and angular, as in ordinary sea sand; but those that have been rolled about by the wind, as on a desert or a sand dune, may be as well polished and as perfectly rounded as are a boy's marbles.

The two essential qualities of sand are that the grains must be loose, and that they must be more than .05 of a millimetre, or more than one-five-thousandth of an inch in diameter. If the grains be smaller, the material is a clay. If the grains be fastened together by some cement into a firm coherent rock, then the material is changed from sand into sandstone. If the cement be so firm that the rock breaks with a smooth instead of a rough surface, the fracture passing through the sand grains as easily as around them, the rock, if siliceous in composition, is called a quartzite.

In an ordinary sandstone the grains are small. If the grains are larger, the rock is known as a grit, like the millstone grit. If they are as large as pebbles, the rock is either a conglomerate, if the pebbles be rounded and angular, or a breccia if they be angular. Conglomerate and breccia are cemented gravel or pebble beds, just as sandstone is cemented sand.

The Argillaceous Series.—The typical member of the argillaceous series is clay, and the essential feature of a clay is that it is so fine grained that when moistened it is soft and plastic. This property belongs to most materials of which the grains are less than one-five-thousandth of an inch in diameter. Most clays, however, are formed of fine particles of decomposed felspar, and they consist chemically of a silicate of alumina combined with water. But clay substance may consist of other materials, such as quartz ground so finely that when rubbed between the fingers it feels soft like flour.

Most clay is deposited by water on the floor of seas or lakes, or in the quiet parts of river channels; it is then usually saturated with water, and contains much organic matter, and is known as mud.

A clay so compact that it cannot be broken in the hand and is not plastic, until after it has been ground to powder, is a mudstone or claystone.

Clay is deposited under water in successive layers, and when the clay is dried and slightly compressed, it generally breaks readily along the planes between these layers; this variety of clay is known as shale.

If clay be subjected to heavy pressure, the constituents are rearranged so that all the particles lie with their larger surfaces parallel, and at right angles to the direction of the pressure. The rock may then split readily into thin smooth slabs; rock in this condition is known as slate, and the property by which it thus divides is its slaty cleavage.

A mixture of sand and clay is a loam; and a mixture of clay with calcareous material is known as marl. If the sand, sandstone, or clay contain abundant flakes of mica, it is then said to be micaceous; if it contain much iron, it is a ferruginous rock or ironstone.

CHAPTER VII

CHEMICALLY FORMED ROCKS

In addition to the stratified rocks that are formed directly of redeposited fragments of igneous rocks, there are two kinds of rocks which are secondary in the sense that their materials are derived from the primary rocks; but this origin is less obvious, as the material has been removed from the igneous rocks in solution, and extracted from the water that dissolved it by some chemical reaction or by living beings. The rocks are therefore known as either chemically deposited or organically deposited.

The chemically deposited rocks are comparatively small in quantity, but they are important owing to their high economic value. They may be classified according to either their composition or mode of formation. Under the first system these rocks are divided into the calcareous—those formed of carbonate of lime; the siliceous—those formed of silica; the ferruginous—those rich in iron; and the carbonaceous—in which the most important element is carbon. Under the second and more convenient system there are rocks formed (1) by chemical reactions; (2) by the evaporation of the water from lakes or lagoons; (3) as an efflorescent crust on the land by the evaporation of solutions rising from underground.

1. *Chemically deposited Carbonates.*—The most widely distributed rock that has been formed chemically is composed of carbonate of lime. Its formation is so important that it is advisable to follow the process carefully. The lime present in igneous rocks is usually present as a silicate of lime; water containing some dissolved carbonic acid (CO_2)[1] which it has obtained from the air acts upon the mineral, decomposes the silicate of lime, and removes the lime as bicarbonate of lime (composed of one molecule of lime, CaO, combined with two molecules of CO_2), which is soluble in water.

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[1] CO_2, carbonic dioxide, in accordance with the usual practice of geologists, is here called carbonic acid; but it is not, strictly speaking, an acid until combined with water.

The reactions are shown as follows—

$$\underset{\text{(Silicate of lime)}}{CaO,SiO_2} + \underset{\text{(Carbonic acid)}}{2CO_2} + \underset{\text{(Water)}}{H_2O} = \underset{\text{(Silica)}}{SiO_2}\text{[1]} \quad \underset{\text{(Bicarbonate of lime)}}{CaO,H_2O,2CO_2}\text{[2]}$$

An analogous process happens when water containing carbonic acid in solution acts upon limestone, which is composed of one molecule of lime (CaO) combined with one molecule of carbonic acid or carbon dioxide (CO_2). Its formula, therefore, may be written either $CaCO_3$ or CaO,CO_2. As it contains only one part of carbonic acid united with one part of lime, it is a unicarbonate; and unicarbonate of lime is insoluble in water. If water containing carbonic acid passes into a bed of limestone, the carbonic acid unites with some of the unicarbonate of lime and converts it into the soluble bicarbonate of lime which is removed in solution. If this water be subsequently exposed to the air, the extra molecule of carbonic acid may escape, with the result that the lime compound is altered to the

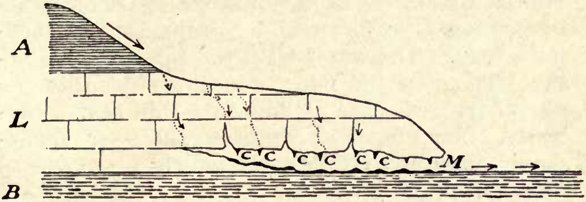

Fig. 5.

A Cave formed by solution of Limestone (L). A and B are layers impermeable to water. c, stalactites on the roof of the cave, beneath which are the humps of stalagmite on the floor. M, mouth of the cave.

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[1] Left behind as particles of quartz.

[2] Removed in solution.

insoluble unicarbonate, and deposited as a layer of carbonate of lime. Thus, when water, after percolating through limestone, reaches a cave, the drops of water hang upon the roof; the extra molecule of carbonic acid is given off, and the carbonate of lime deposited. More such water oozing from the same place deposits more carbonate of lime, and gradually forms from the roof of the cave a pendent, called a stalactite. The beauty of caves in limestone districts is due to the fantastic forms and translucency of these stalactites. The water from the tip of the stalactite falls upon the floor, and there deposits the rest of its carbonate of lime in a thin film. Successive films form a compact sheet or dome-shaped humps of limestone, which is known as stalagmite (Fig. 5).

When a spring issues from a calcareous rock, there also the water may deposit carbonate of lime, as in a slight crust on any substance over which the water spreads in a thin layer, thus exposing a wide surface to the air. Such springs are popularly known as petrifying springs. The carbonate of lime deposited by spring water around twigs and mosses sometimes accumulates as beds of porous limestone, known as calcareous tufa. The precipitated carbonate of lime may, however, be carried away in fine particles by the stream from the spring, and deposited in some quiet pool or lake as a bed of chemically formed limestone.

Other materials, as well as lime, have a soluble bicarbonate and an insoluble unicarbonate, and chemical deposits of these materials are formed by analogous processes. The most important are some deposits of carbonate of iron.

Another kind of chemically formed rock is due to water containing a solvent percolating through a rock and dissolving one of its constituents. The dissolved matter may be deposited as nodules or masses in spaces existing in the rock; the spaces may be formed by particles of a rock being dissolved and replaced, almost at once, by fresh material. Thus water containing alkali will dissolve silica, which it may redeposit as lumps or nodules of "chert." Carbonate of magnesia may be carried into limestones, and there, combining with some of the carbonate of lime, converts the limestones into the rock known as dolomite.

2. *Ore Deposits.* — The solution of particles widely scattered through rocks and their collection or "segregation," either in a fissure or in large masses, is the process to which we owe the majority of ore deposits. Most metal-bearing veins or lodes are due to hot solutions that have arisen from a great depth below the earth's surface, where they dissolved particles of various metals. As the solutions approached the surface they were cooled, and the minerals dissolved in them deposited along their channels as mineral lodes or veins.

Some ore deposits, especially iron ores, are formed by water soaking downward from the surface and depositing iron collected from the overlying rocks.

Mineral lodes formed near the surface of the earth generally contain carbonates, such as carbonate of lime. The deeper ore deposits generally contain much quartz, mixed with various metals or metallic compounds scattered through it.

Many of the larger ore deposits occur as vast masses of an irregular egg-shaped or lens-shaped form. They cannot have been formed in cavities, as no spaces so large could have remained open deep within the earth. They are due to the replacement process. Solutions have removed the original rock, particle by particle, replacing each at the same time by ore.

3. *Deposits formed by Evaporation.*—A third series of chemically formed rocks are those produced by the evaporation of sheets of water, such as lakes, or former arms of the sea which have been completely enclosed by land. Rivers are constantly adding mineral matter to the sea, and to lakes which have no outlets. This material accumulates until it amounts to an average in the water of the existing seas of about 3½ parts of mineral matter in every 100 parts of water. This 3½ per cent. is composed of the following constituents—

Salt (sodium chloride)	77.8
Chloride of magnesium	10.9
Sulphate of magnesium	4.7
,, lime	3.6
,, potash	2.5
Bromide of magnesium	.2
Carbonate of lime	.3
	100.0

During the evaporation of sea water the least soluble of its salts are deposited first, and the most soluble last. Sulphate of lime is much less readily dissolved in water than common salt. Hence as the water evaporates the sulphate of lime is deposited first, and forms beds of gypsum. Later on, if all or nearly all the water be removed, chloride of sodium is deposited as common salt.

Rock salt is the chief source of the common salt (sodium chloride) used in the British Isles; it is obtained from beds in Cheshire and Worcestershire on the sites of old lagoons. Sulphate of lime combined with water forms gypsum, commercially valuable since plaster of Paris is prepared from it. The massive varieties, some of which are streaked with pink veins due to colouring by oxide of iron, are known as alabaster and are worked as an ornamental stone. Alabaster is easily carved, being so soft that it can be scratched with the thumb-nail.

The evaporation of lakes lays down beds of gypsum and salt, and of other materials, such as carnallite (chloride of potassium and magnesium) and natron (carbonate of soda).

4. *Efflorescent Rocks* comprise a fourth series of chemically formed rocks. They are due to solutions containing various materials being sucked up to the surface of the earth by capillary attraction and there evaporated. They may then form a thin crust of limestone, carbonate of soda (thermonatrite), ironstone, or chert. Efflorescent rocks are not common in countries with a wet climate, for they would be washed away as quickly as they were formed; but in arid regions, where evaporation would remove more water than falls as rain, these efflorescent rocks are very widespread. In some places they enrich the soil by bringing up plant food from below; but in other cases they are fatal to agriculture by covering the surface with a layer of hard chert, or saturating the soil with some injurious constituent.

CHAPTER VIII

ORGANICALLY FORMED ROCKS

THESE rocks are due to the action of animals and plants which extract various materials from water, soil, or air, and fix them in their skeletons, shells, or hard tissues. After the death of the animals or plants their hard parts may endure, and if buried and thus preserved they are known as fossils. Fossil remains may accumulate in sufficient quantities to form entire beds of rock of great thickness. Some organically formed limestones are thousands of feet thick, and extend over many thousand square miles. Such vast sheets of limestone cannot have been deposited chemically from sea water, as it does not contain enough carbonate of lime. Sea water contains, on an average, 3.6 parts in 100 of sulphate of lime, and only one-eleventh of that quantity of carbonate of lime. Animals that live in the sea and have shells of carbonate of lime obtain their lime from the sulphate; for they have been observed by Sir John Murray to live and form their shells in water, from which all the carbonate of lime has been artificially removed. They convert the sulphate of lime into carbonate of lime by a chemical reaction—

$$\underset{\substack{\text{(Sulphate}\\\text{of lime)}}}{CaSO_4} + \underset{\substack{\text{(Ammonium}\\\text{carbonate)}}}{Am_2CO_3} = \underset{\substack{\text{(Carbonate}\\\text{of lime)}}}{CaCO_3} + \underset{\substack{\text{(Ammonium}\\\text{sulphate)}}}{Am_2SO_4}$$

produces ammonium sulphate and carbonate of lime—

that takes place in their bodies.

Many different kinds of animals and plants form hard skeletons, which after death remain as the constituents of organically formed rocks. Some animals form skeletons of carbonate of lime and give rise to calcareous rocks; others, as, for example, some sponges, have their hard parts of silica, and form siliceous rocks; many plants have tissues of carbonaceous material, and give rise to beds of peat and coal.

Organically formed Calcareous Rocks.—The most numerous animals that have skeletons of carbonate of lime belong to the group of the Mollusca, which includes the ordinary shell-fish, such as the oyster, cockle, mussel, whelk, and the land snails. Mollusca are abundant in the sea, in lakes, in rivers, and on land. They often live in colonies, such as oyster beds, and on the death of the animals their hard shells accumulate as shell beds. The spaces between the shells may be filled by shell fragments, or all the shells may be broken into small particles forming shell sand. Water subsequently percolating through the mass may cement it into a firm rock.

Corals that live in shallow water in tropical seas have thick skeletons of carbonate of lime, and as they grow in colonies, they form masses of coral limestone known as coral reefs. These reefs sometimes form islands, and sometimes long breakwaters skirting the shore.

Sea lilies (Crinoids) are a group of animals allied to the starfish. Most of them live attached to the sea floor by a long flexible stem composed of many short joints of dense carbonate of lime. The stems are sometimes 100 feet in length, and on the death of the sea lily the joints of the stem fall apart and are scattered over the sea floor. They are called St. Cuthbert's beads, and form beds of limestone known as crinoid limestone, of which some kinds, such as the Derbyshire marble, are worked as ornamental stones.

The Bryozoa, so named from their moss-like appearance, are small compound animals; they often grow in dense clusters, and their small stem fragments form bryozoal limestones. The Foraminifera are minute animals of a very simple organisation; most of them have a shell of carbonate of lime; they live in great abundance on the sea floor or on the sea surface. Their dead shells accumulate to form a widespread sheet of calcareous earth known as foraminiferal ooze, which covers vast tracts of the ocean bed. These foraminiferal deposits may be consolidated into limestones, and some of the most important and best-known limestones are principally composed of foraminiferal shells. The Pyramids are mainly built of such limestone, but the Foraminifera in them are of a comparatively gigantic kind, forming thin discs about as large as a penny.

Plants also help in the formation of limestones. The oolitic limestones, which are largely used in England for building-stone, are composed of small rounded grains, so that the rock resembles the hard roe of a fish. These grains were at first thought to have been formed chemically by the repeated evaporation of sea water that had moistened beds of sand, a thin film of carbonate of lime being deposited on each occasion. This process is chemically improbable owing to the scarcity of carbonate of lime in sea water; and the microscopic study of these oolitic grains shows that they have been formed by seaweeds or algæ, which extract lime from sea water and deposit it as carbonate.

Organically formed Siliceous Rocks.—Organically formed siliceous rocks are due to the action of organisms which build their skeletons of silica. Many sponges have skeletons composed of minute rods or spicules of silica. The spicules left after the death of the sponges on a sponge bank may accumulate and be cemented into chert. Radiolaria are primitive animals closely related to the Foraminifera, from the typical kinds of which they differ by having shells composed of silica. The existing Radiolaria mostly live far from land in the tropical oceans; their dead shells form deposits of radiolarial ooze widely spread over the ocean floor. Some kinds of chert are radiolarian ooze cemented into a hard rock.

Many lakes, as well as the colder seas, are inhabited by vast swarms of minute plants, known as diatoms, which have a shell composed of silica. Their shells accumulate on the floors of the oceans as a diatomaceous ooze, and in lakes they often form thick deposits of almost pure siliceous powder. This material is used for polishing stone and metal under the name of Tripoli Powder.

The plants known as Algæ extract silica from the waters of hot springs, and deposit it in crater-shaped mounds or terraces, which are often of exquisite beauty. This variety of siliceous rock is known as sinter. The " Pink and White Terraces " of New Zealand are the most famous and were probably the most beautiful of these sinter formations; but they were destroyed by a volcanic explosion which blew them into fragments during the eruption of Mount Tarawera in 1886.

Phosphatic Deposits.—Deposits of phosphate of lime are much scarcer than those of carbonate of lime, but they are of great economic value as one of the chief sources of artificial manures. One of the best known is guano, which is composed of the droppings of sea birds on small islands in arid regions. Fish are rich in phosphorus, and contain more than the birds which prey upon them can assimilate; the rest passes from the birds in their dung. The droppings fall mainly around the nests and breeding-places. The birds cannot assemble for breeding in large numbers on the mainland, or they would be preyed upon by animals and their eggs devoured by snakes. The chief breeding-places of sea birds, therefore, are usually on small islands.

Guano, moreover, can only form where there is a small rainfall, as otherwise its valuable constituents would be washed out and carried to the sea; it is therefore a rare deposit, because it can only accumulate under exceptional geographical conditions. The chief supplies have come from the Guano Islands off the western coast of South America, in the Central Pacific, from islands off south-western Africa, off the Australian coast, and in the West Indies.

If a bed of bird-droppings be soaked by rain, the water dissolves the soluble constituents, including the phosphoric acid, and carries them down into the underlying rocks; there the phosphoric acid reacts with one of the constituents of the rock, and forms a phosphate rock. If the island be of coral limestone, the carbonate of lime is altered into phosphate of lime; if it be a volcanic island, some of the earthy minerals are converted into aluminium phosphate. Guano, as distinguished from rock phosphate, can be used at once as a manure; but the rock phosphates require chemical treatment, so that their phosphoric acid may be rendered soluble by water, and thus made available as a food for crops.

Some phosphatic deposits are formed by accumulations of bat dung in caves, or by the accumulation of bones, which are composed mainly of phosphate of lime. Bones often collect in swamps in which animals are bogged during their efforts to get to water, and in lakes into which dead animals are washed by floods. Coprolites, the fossil dung of large land animals, are also a source of phosphate.

Many igneous rocks contain small crystals of apatite, a mineral composed mainly of phosphate of lime. These crystals are dissolved and their material carried in solution to the sea, where the phosphoric acid may act upon minute calcareous organisms and convert them into grains of phosphate of lime. The accumulation of these grains may form beds of phosphatic limestone or phosphatic chalk.

Carbonaceous Rocks.—The last group of organically formed rocks includes those formed from plant remains; they are known as carbonaceous rocks, as carbon is their chief constituent. They are invaluable as our chief source of fuel. All vegetation contains a considerable proportion of the element carbon. Where leaves and branches of trees accumulate on the floor of a forest, they form a leaf mould rich in carbon. The growth of mosses in swamps forms a spongy, sodden mass, which dries into the material known as peat. If forest mould, or a bed of peat, be buried beneath a layer of sand or clay, the carbonaceous layer would be preserved and represent the first stage in the formation of a coal seam. Wood dried in the air contains about 20 per cent. of water, and the rest consists of 1 per cent. of ash, 39 per cent. of carbon, 4½ per cent. of hydrogen, and 35½ per cent. of oxygen. Air-dried peat contains on an average 16 per cent. of moisture, 8½ per cent. of ash, 44½ per cent. of carbon, 4½ per cent. of hydrogen, and 26½ per cent. of oxygen (including a little nitrogen). If either leaf mould or peat be subjected to combined heat and pressure, the volatile constituents pass away, so that the material is left with a higher percentage of carbon. Soft, spongy peat may be compressed into the harder and more compact fuel known as lignite or brown coal, which contains, on an average, about 15 per cent. of moisture, 10 per cent. of ash, 45 per cent. of carbon, 3¾ per cent. of hydrogen, and 26¼ per cent. of oxygen. Increased pressure may convert the brown coal into ordinary black coal, or, as it is often called, bituminous coal; it contains, on an average, 3 per cent. of moisture, 10 per cent. of ash, 72 per cent. of carbon, 4 per cent. of hydrogen, and 11 per cent. of oxygen. If still more of the volatile constituents be removed, leaving a material with 3 per cent. of ash, 2 per cent. of moisture, 91½ per cent. of carbon, 2½ per cent. of hydrogen, and 1 per cent. of oxygen, the coal has been converted into anthracite or smokeless coal. This is much harder than ordinary coal; it has a bright lustre, and when free from dust does not soil the hands. It is not readily ignited, but when once lighted, burns without smoke or flame and gives a more intense heat than ordinary bituminous coal. It is often known as steam coal, and being smokeless is especially adapted for naval purposes, as the presence of a fleet using it would not be betrayed by smoke. If bituminous coal or anthracite be subjected to intense heat, as by contact with a dyke of igneous rock, the coal is converted into coke or graphite, which consists of almost pure carbon; the whole of the volatile constituents have been driven off, just as coke is formed in a gas-works by driving off the gas from coal.

It is not certain that the difference between bituminous coal and anthracite is always due to the latter having been subjected to greater heat and pressure, for both materials occur together, where they must have been subject to the same influences. In these cases the two kinds of coal have probably been formed from different kinds of vegetation.

The gradual transition from vegetable matter to graphite is shown in the following table, which summarises the figures given in the previous paragraphs—

	Carbon.	Hydrogen.	Oxygen.	Ash.	Moisture.
	per cent	per cent	per cent	per cent	per cent
Air-dried wood	39	4.5	35.5	1	20
Air-dried peat	44.5	4.5	26.5[1]	8.5	16
Air-dried brown coal	45	3.75	26.25	10[2]	15
Bituminous or black coal	72	4.0	11.0	10[2]	3
Anthracite	91.5	2.5	1.0	3	2
Graphite	95	—	—	5	—

Oil shale and cannel coal are two varieties of coal much richer in oils than bituminous coal. When heated they give off the hydrocarbons, such

[1] Includes a little nitrogen.

[2] Very variable.

as mineral paraffin, which consists of 86 per cent. of carbon united with 14 per cent. of hydrogen. Some hydrocarbons are found in fissures and veins, and they are probably due to distillation from carbonaceous rocks. The richness of oil shales in hydrocarbons is probably due to the abundance in them of spores or small water weeds, instead of the woody tissues of plants and trees that form ordinary coal.

The oils, such as petroleum, which spout to the surface of the earth in many regions, such as Baku on the Caspian and the oil fields of America, have probably been distilled from underlying carbonaceous deposits. The most volatile constituents sometimes escape at the surface as natural gas. This gas may accumulate in a porous layer below some impermeable rock, and when this cover is pierced by a bore-hole the gas escapes to the surface, and affords a supply of cheap heat and light. Oil shale, such as that of southern Scotland, contains oils which have to be driven off by heating the shale in large retorts.

CHAPTER IX

THE METAMORPHIC ROCKS

In addition to the ordinary primary and secondary rocks there is a group intermediate between them and combining some of their characteristics. Thus this group includes rocks which, like those of the primary division, are composed of crystalline material, and are unfossiliferous; they agree with the secondary rocks in that their constituents are arranged in layers. This banded structure is, however, not due to original deposition of the materials in successive layers. It is sometimes due to molten rocks having solidified slowly, while they have been flowing under great pressure. It is sometimes due to a rock having been so altered by heat and pressure that its particles have been completely rearranged, all its original constituents having been converted into new minerals. The new minerals have grown with their longer surfaces parallel, and thus the rock breaks into slabs, like slate. As this splitting is due to the crystalline structure of the rock, it is called crystalline cleavage or foliation, to distinguish it from the splitting of slate, which is due to slaty cleavage. The foliated rocks, and those in which the constituent minerals have been formed in the rock by the alteration of a previous mineral, constitute the metamorphic group.

The process of metamorphism is due to three chief causes—contact with molten rocks, deep subsidence in the earth's crust, and dynamic action. They are known respectively as contact-metamorphism, thermo-metamorphism, and dynamo-metamorphism. Contact-metamorphism occurs along the junction of a molten rock mass with some older rock, which is altered by the heat. Thus a granite mass that has been forced into a series of older rocks is usually surrounded by a zone of altered rocks, known as its contact aureole. Thermo-metamorphism is probably due to the rocks of a wide region sinking so deeply below the earth's surface that they are intensely altered by the combined effect of the intense heat and pressure. As this action affects all the rocks in a wide area, it gives rise to regional metamorphism.

Dynamo-metamorphism happens during the great earth movements that accompany the formation of mountain chains. Bands of rock are ground to powder along the planes of movement, and others, perhaps less severely crushed, have their constituents recrystallised by the heat.

The term "metamorphism" is strictly confined to processes which only rearrange the constituents of a rock and do not add to or remove any of them. Metasomatism, on the other hand, involves an actual change in the constituents of the rock. There is usually a replacement of one or more of the original constituents by fresh material; the process may be due either to hot solutions soaking through the rock, or to the absorption by one rock of some constituent from another. A sandstone, consisting only of silica and alumina, cannot produce a mica-schist; but if alkalies be added to it in solution from an adjacent granite, then the sandstone may be altered into mica-schist. Metasomatism plays a very important part in the formation of mineral lodes.

The chief metamorphic rocks are—

(1) Gneiss, which consists of the same minerals as granite, arranged, however, in parallel layers instead of irregularly. Syenite-gneiss and gabbro-gneiss are syenites and gabbros with the same parallel arrangement.

(2) Schists have their minerals in thinner layers than gneiss, so that the rock has a slate-like aspect. The schists are known as mica-schist, hornblende-schist, etc., according to their characteristic mineral.

(3) Marble is a metamorphic rock which is usually non-foliated; it is an altered limestone. The term " marble " is, however, often applied to any rock that can be easily cut and polished.

(4) Quartzite is an altered sandstone.

PART III

PHYSICAL GEOLOGY

CHAPTER X

THE WEARING AWAY OF THE LAND

THE first natural impression formed of a mountain or a hill, when we stand beside it, is one of vast size and apparent permanence. The smooth slopes with their thick carpet of old turf and the ribs or crags of rocks that may here or there break the evenness of the surface, have the aspect of antiquity and durability. Though it is clear, even on a casual inspection, that the hills have changed, gradually growing into their present shapes; though we can see the gullies on the hill-side are still being deepened and widened; and the very existence of the rough crags implies the wearing away of the softer rocks beside them, yet these processes are so slow that they appear negligible. Even the earthworks of prehistoric man on the hilltops, and the tracts and paths that led to his ancient camps, are often still distinct and have not been worn away, though the rock may be as soft as the chalk of the English Downs; while the quicker changes wrought by man in railway cuttings or prolonged quarrying are so insignificant compared with the bulk of the hills, that there seems little exaggeration in the poetic language which speaks of the "everlasting hills."

This expression, however, judges the hills only by comparison with the short life of man, and not with the slow processes of geological change, by which a country has grown into its present form. Study of the structure of the mountains soon dispels any idea of their immutability and immortality, and shows that they are only the remnants of once larger rock masses; and mountains usually give more striking evidence of change than of indestructibility. The geological structure of many mountains, as, for example, Snowdon, shows that they are the last fragments of a great fold of rock; the mountain summit was originally the bottom of a valley, between hills which have been all removed, and replaced by valleys so cut, that what was originally the floor of the valley has been left as a mountain summit.

The North Downs, south of London, show a good example of this process (Fig. 6). Looking southward from their summit across the valley of the Weald, there may be seen another line of chalk hills, forming the South Downs. The floor of the valley between is occupied by rocks older than the chalk; these rocks have been exposed by the removal of the thick sheet of chalk that once rose in a vast arch across the country that is now occupied by the broad valley of the Weald.

Geology shows that most hills are only fragments of once larger hills. The agents that have worn them down to their present size work slowly; but they effect great changes owing to their untiring and often unceasing attack. The whole land is crumbling, for while some agents cause the decay of any rocks exposed on the surface of the earth, other agents remove the decayed material, uncovering deeper layers which are destroyed in turn. This process is known as Denudation.

The chief agents of denudation are air and water, and the changes in temperature between night and day. Rocks exposed to the atmosphere suffer from the changes caused by expansion and contraction, as they are warmed in the daytime and cooled at night. Granite readily cracks when it is alternately expanded and contracted by heat, for the three minerals of which it is composed expand at different rates, and thus the rock is torn by numerous fissures. In dry, hot climates a continuous crack forms parallel to the surface, causing the outer part of the rock to break off in large thin slabs; this flaking causes granite in tropical and sub-tropical countries to wear into even, dome-shaped masses, which have often been mistaken for the smooth, rounded hummocks formed by ice. The shattering of rocks by sudden cooling is practised in primitive quarrying and mining by people who have no explosives or machine tools. A fire is lighted on the surface of rock in a quarry, and the heat cracks off a large slab. Or a fire is placed at the end of a tunnel in a mine, and the heated rock is suddenly cooled by being drenched with water, which causes the rock to crack and fly to pieces.

In countries with a moist atmosphere the rocks are cooled and warmed more slowly, so that they are less severely cracked; but the rain water soaks into pores and cavities in the rocks, and when the rock is cooled below freezing-point (32° F.) the water is frozen, and its expansion forces off flakes of the rock. Such flakes are

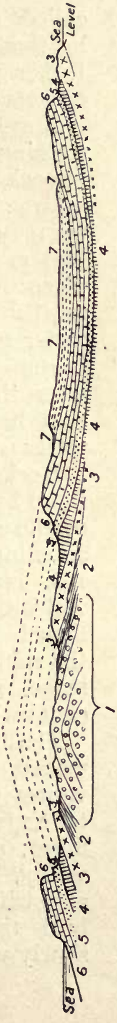

Fig. 6.—Section from the Hertfordshire Downs to the English Channel through the Thames Valley near London. The numbers show the relative ages of the beds, No. 1 being the oldest. No. 6 is the Chalk. 7 includes the London Clay.

called frost flakes. Similar flakes, due to sudden heating by the sun, are known as insolation flakes. Either process slowly breaks off the outer layer of a rock and exposes a fresh surface to attack.

A still more powerful effect is produced by the freezing of water in the large cracks and fissures in rocks. The expansion of this water may force a large block of rock out of a cliff face, and its fall may smash and scatter the loose material at the foot of the cliff. Alpine climbers have to avoid places swept by such rock-falls. They occur mostly either shortly after sunset, when the water freezes in the cracks, or after the sun has begun to warm the cliff face in the morning, when the melting of the ice releases blocks of rock that have been pushed forward by the freezing water of the previous evening.

Rocks are also destroyed by dust hurled against them by the wind. This action is similar to that of the sand-blast; this machine, by a current of air, flings a jet of sand against a surface, which is thus rapidly worn away. A jet of soft powder will wear away a much harder material. Wheaten flour blown against glass will cut it away, just as the rubbing of a rope will cut a groove in sandstone, as may often be seen in walls beside a canal where the tow-ropes rub perpetually.

The wind will sometimes blow with high velocity; even in a gentle breeze the air advances eighteen miles an hour, and in a gale up to sixty-five miles, and in a hurricane ninety miles; and where the wind is confined in a narrow valley, its speed may be much increased. The air swiftly bears along hard grains of sand and hurls them against bare rock surfaces, which are slowly worn away. As most of the dust is carried along close to the ground, sand erosion is most effective at the foot of a cliff, which is thus undercut, so that its upper part falls over. Sand erosion has its greatest effect upon materials that are rigid and inelastic; for soft elastic material will yield, and on its rebound fling off the sand grain, whereas a harder, less elastic material will be cut away. The removal of the less elastic material in a cliff or in a rock leaves an irregular surface, which is open to attack from other agents.

Water is the most powerful agent in denudation; it works in the form of rain, of rivers and seas, and also, when frozen, of ice. Rain, falling on rocks, soaks into pores and crevices, and if this water freeze at night, its expansion tends to shatter and disintegrate the rock. In addition to thus forcing the particles of the rock apart, the water has also a solvent effect. Rain water always contains some gases which it has obtained from the atmosphere, and they combine with the constituents of the rocks, thus forming new materials. The chief gases are oxygen and carbonic acid, which combine with the constituents of the rocks to form oxides and carbonates. This chemical change, by causing expansion, therefore helps the crumbling of the rock. Some of the constituents of a rock may, on the other hand, be dissolved and removed in solution, leaving the rock more porous, and still more open to the entrance of air and water.

The water entering the rocks by numerous openings on the surface unites as it percolates downward, until it may finally form subterranean streams; and if they reach beds of any soluble rock, such as limestone or beds containing salt or alum, these materials are carried away in solution, leaving caves and empty spaces.

The rain that does not percolate underground flows over the surface and collects into rills of water, and they in turn unite into streams. The streams unite to form rivers. The rivers are probably increased by receiving water that has percolated underground, and discharges through springs on the bed of the river.

Running water, alike in rills, streams, and rivers, attacks and wears away the rocks over which it flows. It attacks them in two ways—mechanically and chemically. The chemical process is the solution of the soluble constituents of the rock, as sugar can be separated from sand by washing a mixture of the two with water. The mechanical action is the removal of the material bodily, as a stream carries away leaves and twigs. The mechanical action is aided by the chemical, which, by removing the cement from a rock, causes its grains to fall apart, and they can then be removed mechanically. Rain washes away grains of sand and clay, so that the water becomes muddy.

The excavating action of streams and rivers is conveniently divided into two kinds—the wearing away of the bed of the river, which is known as corrosion, and the wearing away of the banks, which is known as erosion. Corrosion cuts a narrow gorge (Fig. 11), which erosion widens into a broad valley. The rate of both processes depends largely on the swiftness of the current, for upon that depends the amount of material carried by the river. Pure water has very little power of wearing away hard rocks, but a river loaded with sand soon wears away the rocks over which it flows. Clear river water flowing quickly across clay or soft rocks will rapidly corrode them, for the water softens the surface of the clay or the cementing material in the soft rock, and ascending currents, caused by the eddies, will uplift and remove the loosened material.

A rapid current can carry more and coarser material than a slow current. Hence, the quicker the current, the greater its corroding power. For when coarse material is carried across rocks in the river bed, the sand grains and pebbles act like the teeth on a file. This rasping action is very effective, as the river is always at work, and, owing to its plasticity, its teeth are brought in contact with all parts of its bed, however irregular it may be.

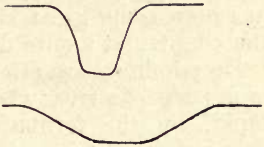

Fig. 7.

Sections through River Valley. The upper valley is a gorge due to corrosion; the lower is a valley widened by erosion.

Corrosion is also aided by floating trees, which strike with great force against rocks on the river bed. Trees, of which the wood is heavier than water, as is the case with many of the trees of Australia, or which are weighted by masses of earth and stones attached to their roots, sink in deep rivers and, drifting slowly along, tear up the river bed.

Rivers often also deepen their valleys by the action of waterfalls. A waterfall occurs where a bar of hard rock crosses a stream. This rock is cut away more slowly than the soft rocks below it, and thus it projects as a ledge over which the water rushes as a cataract or leaps as a waterfall. The splash of the water at the foot of a waterfall wears away the beds beside it, and the upper part is left undercut. Blocks of the projecting rock fall away, and may be flung by the water against the foot of the cliff. Every waterfall is being thus cut backward, leaving a narrow gorge or canyon below the fall. The Niagara Falls are moving upstream on an average of over four feet a year. Every river will in time cut away the hard bars of rock that form waterfalls, which are thus destroyed. There are no rapids or waterfalls on an old river, as they have been cut away. The mere existence of waterfalls on a river, therefore, shows that there has been some great change in the geography of the country at a date which is geologically recent.

Deep hollows are often cut out below waterfalls, or in parts of a river where the current is especially rapid, by the formation of pot-holes. A pot-hole is formed where a large stone is caught in a hollow on a river bed. If the current causes the stone to spin round, it will wear away the underlying rock. The stone acts like a drill and bores its way downward until it is all worn away. Fresh stones will be washed into the pot-hole, and the swirl of the water in the deepening cavity continues the process (Fig. 11). Pot-holes usually occur in groups, and the rock of the river bed may in time be honeycombed. As the pot-holes are widened their walls break down, and thus the river bed is lowered. According to some authorities, the formation of deep, river-cut valleys in hard rocks is mainly due to pot-hole action.

Corrosion deepens a river bed until its incline is so gradual that the water flows along too sluggishly to wear its bed away any deeper, and the current cannot even remove the material that falls on to the river bed from the banks, or is deposited on it after a flood. A river in this condition has reached its "base level of corrosion." Rivers usually flow most quickly near their source, among the hills, where the slope of the country is steepest; and they flow more slowly across the plains in the lower part of their course. Hence the base level of a river is usually a long curve, steep at first, and then becoming gradually horizontal, like the curve of a piece of string when one end is lifted up and the other is lying upon a table. That is the curve of the base level in a simple river; but if the river enters a lake or a plain, and then flows out again, it will have one base level curve above the lake and another below it (Fig. 8).

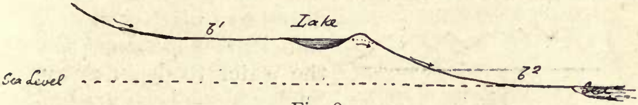

Fig. 8.

Longitudinal Profile along a River Valley. The river has reached its base level b^1, due to the rock barrier that upholds the lake; after escaping from the lake it reaches a second base level, b^2.

As soon as the base level has been reached, a river will begin to attack its banks. The force of the current is directed first against one place and then against another, now against one bank and then against the other. The river washes away the foot of a bank, then the upper part falls into the river. This obstruction diverts the current and directs it against another part of the bank. Meanwhile wind and rain are attacking the river banks, wearing away the upper part of the slope, and transforming a narrow, cliff-bounded gorge to a broad valley with sloping sides. At the same time, tributary streams have been cutting valleys through the adjacent country and lowering their own beds to their base level, which is determined by that of the main stream. Little by little the country alongside the river is lowered to a gentle slope. The waterfalls all disappear, because the bars of rock which formed them are cut through; the lakes are filled up by silt, or else drained by the barrier that upheld the water having been cut away; hills with steep cliffs are worn into hills with smooth slopes, like rounded downs; and finally in the course of ages the hills are all worn away, and the whole country is reduced to a plain with only sufficient slope to allow the water to drain away. Such a slope is so gradual that it is barely perceptible; the country then consists of a plain rising slowly from the sea level or from the rivers to the watershed, which is the line separating the waters flowing into adjacent river systems. As such a river-cut plain is nearly a plane, it is called a peneplane (from the Latin words *pene,* almost, and *planus,* a plane), or peneplain, just as land that is nearly an island is called a peninsula.

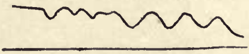

Fig. 9.

Section along an old Peneplane which has been uplifted and destroyed by the formation of valleys across it.

The tendency of river action is to reduce all the land to such peneplanes, and rivers are so powerful and constant in their action that the planing down of the land takes place with surprising rapidity. The Mississippi is said to be lowering the average level of its whole basin at the rate of an inch in about 375 years.

The destruction of the hills and high land is further aided by the action of springs. Rain soaks underground and then flows in subterranean channels; this water moves so slowly that it cannot remove much material in suspension; but the very slowness of its flow increases its opportunity for dissolving any soluble material that it meets on its course. The most widespread material that is soluble in ordinary rain water is carbonate of lime, the essential constituent of limestone. Water percolating through a porous rock may remove all its carbonate of lime; the rock is thereby weakened, and the residue may collapse. Water percolating through limestone dissolves some of the rock along its channel, leaving a long cavity or cave. The widening of the cave at length causes the fall of the roof; and the course of the former cave is marked by a valley with steep, wall-like sides. The rock on the floor of the valley having been shattered by its fall is especially open to the entrance of water, and undergoes solution at an increased rate. Caves thus give rise to those deep gorges which are the most picturesque features in limestone districts.

Underground water aids in the widening of valleys by causing landslips. Water percolates downward through rocks until it reaches an impermeable layer, along the surface of which it moves. If this impermeable bed reaches the surface of the ground on a hill-side, the water discharges along it in a line of springs. The water may wash away the material beside the springs so that the overlying rocks project unsupported, and in time they fall into the valley.

If the rocks are sloping downward into the valley, as in Fig. 10, the underground water, flowing over a bed of clay, makes its surface so slippery that masses of the overlying rocks may slide as a landslip into the valley. Landslips sometimes involve the fall of such enormous rock masses that they form dams across valleys, and the water collects behind them, forming lakes. Landslip action is especially rapid where permeable rocks rest upon a sloping surface of clay.

The land is also being constantly worn away by the sea, which cuts back the cliffs along the shore. The coast of a country is often formed of a line of cliffs rising above a beach of shingle. The shingle consists of pebbles or rolled fragments of the rocks fallen from the adjacent cliffs. In storms, the waves not only themselves batter the cliff with terrific violence, but as they break upon the beach they hurl against the cliff face the pebbles whose oft-repeated blows help to wear it away. The battering action is aided by an explosive effect. Air is forced into any cracks in the rocks and there compressed by the blow of the

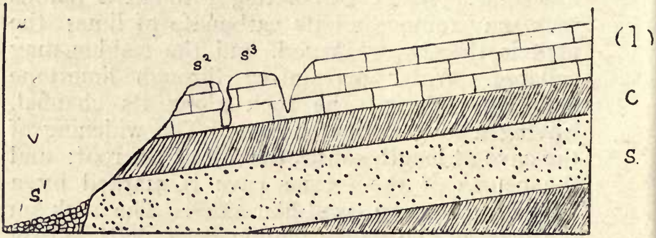

Fig. 10.

A Bed of Limestone (*l*) resting on a Bed of Clay (*c*) above Sandstone (*s*). The rocks are dipping into the valley (*v*). Water percolating through the joints in the limestone make the upper surface of the clay slippery; and masses of the limestone slip downward in landslips. s^1 is the remains of a fallen mass; s^2 is wholly, and s^3 partly detached.

wave. When the wave falls back from the cliff, the air in the crevices suddenly expands with such violence that blocks of rock may be jerked from their place and added to the beach material below. While the cliffs are being cut slowly backward, the sweep of the surf to and fro under the influence of tide and wind planes the shore

Fig. 11.

The Finart Glen. A Stream Gorge cut by corrosion. The circular eddy on the left side of the stream is due to a pothole in process of formation. The rocks are sandstones at the base of the Carboniferous System. (*By J. W. Reoch.*)

to a level platform. This platform is increased in width until it forms a " plain of marine denudation." The level surface may be broken here and there, where a hard block of rock resists the action of the surf and stands up as a rock " stack." Some stacks are so large that they form islets. Both stacks and islets slowly crumble as the waves undermine their cliffs.

Ice Action.—Water also acts in many parts of the world in the form of ice. In the Arctic and Antarctic regions the surface of the sea is frozen. Sheets of ice or " ice floes " are thus formed, and they may be ten feet in thickness. Vast fields of such ice are blown by the wind against the land, and as they drift ashore they churn up the beach materials and are forced by the pressure of the ice behind to the height of fifty feet or more above sea level. The impact of the grounding floe may knock large blocks of rock off the cliffs; and as the lower surface of the ice becomes charged with stones and dirt from the beach, it grinds away and polishes the rocks along the shore.

The tropical and temperate regions of the world have too warm a climate for ice to exist on the lower country; but as the temperature falls about 1° F. for every 300 feet of ascent above sea level, the air on high mountains is always cold. The moisture from the clouds falls on them as snow and not as rain. Where more snow falls than is removed by evaporation or melting, the mantle of snow increases in thickness and the lower layers are by pressure converted into ice. Ice formed in this way is composed of small grains, and owing to the movement between these grains the ice is plastic. Such ice, if formed upon a mountain side, flows slowly down the slope just as a block of pitch will in the course of months flow down a sloping board.

As rain water collects in streams and flows along the valleys, so ice flows along the valleys and forms rivers of ice, which are known as glaciers.

Fig. 12.

An Alluvial Flat on the site of a former Lake. The lake was formed by the deposition of the bank of moraines, seen just above the middle of the view. The moraine has been cut through and the stream and the lake thus drained. The rocks in the foreground are Old Red Sandstone. (*By J. W. Reoch.*)

The ice may be so thick and widespread that it may bury the whole of a country beneath a continuous sheet. Such an ice cap now occupies the interior of Greenland, and another covers the Antarctic continent. In Europe the ice occurs as glaciers, which usually flow as well-defined rivers of ice.

Glaciers corrode and deepen their valleys as rivers do. Pure glacier ice would probably have little power of wearing away rocks, but the lower layers of a glacier are usually charged with stones and dirt. Some of this stony material falls on to the glacier from the sides of the valley, and is washed to the bottom of the ice down deep cracks or crevasses, which are formed where the flow of the ice is irregular owing to a bend in its course or a sudden increase in its slope. More of the stony material is picked up from the ground beneath the ice. The sole of the glacier is therefore rough owing to the presence of these included rocks fragments; and as they are carried forward, they press against the ground, dig into the soft material, and file away the hard rocks. The stones in the ice are scratched by being rubbed against the underlying rocks and against one another. When the glacier reaches a level where the temperature is so warm that the ice melts away as quickly as it is renewed by a flow from above, the material in the glaciers is deposited in heaps known as "terminal moraines" (Fig. 12). They usually include a motley assemblage of the harder rocks which the glacier passes in its course, and many of the stones have ground and ice-scratched surfaces.

The former existence of glaciers can be recognised in countries from which they have long since disappeared by the presence of the ice-scratched stones, and of rock surfaces that have been polished by the passage of ice across them. As these humped and hollowed rock surfaces have been compared to the curls of a lawyer's wig, they have been called *roches moutonnées*, from the French word *moutonner*, to crimp or wave.

In the colder regions of the earth the glaciers may flow downward till they reach the sea. Vast blocks of ice are there broken off from the glacier and float away as icebergs. They may carry boulders and quantities of earth and stones, and, as the ice melts, drop them in far distant localities. Icebergs from the Antarctic have been seen in the South Atlantic within only a few miles of the tropics, and large icebergs from the Greenland seas drift into the North Atlantic as far south as the steamer route between British ports and New York. Large boulders transported to a distance by ice, whether by iceberg or glacier, are known as "erratics," and they often give valuable evidence as to the former movements of the ice.

Glaciers, like rivers, wear a country away. They lower their beds by corrosion, and also widen their valleys by erosion of the banks. As ice is less fluid than water, a glacier adapts itself less readily than a river to bends in its course. The glacier ice therefore presses against spurs that project into its valley, and slowly cuts them back; hence a glacier flowing into a sinuous, river-cut valley tends to cut it straighter. Valleys that have been occupied by glaciers resemble regular, steep-sided troughs; while valleys cut by rivers are sinuous, have numerous bends, and, unless young, have gradually sloping sides.

CHAPTER XI

HOW SECONDARY ROCKS ARE DEPOSITED

THE materials obtained from the destruction of the primary rocks are reformed into the various rocks described in Chapters VI., VII., and VIII. These new rocks vary in character according to their deposition, whether it is on land, in rivers, in lakes, or in the sea.

SUBAERIAL DEPOSITS

The deposits formed on land are of four chief kinds—Soil and Subsoil, Talus, Dunes, and Loess.

Soils and Subsoils.—The most widespread land deposit is the ordinary soil. Rocks exposed to the action of the atmosphere and of rain water are gradually decomposed. The soluble constituents may be removed in solution, and the rest is disintegrated by the oxygen of the air uniting with some of the constituents to form new compounds. The rock thus gradually crumbles to pieces. The entrance of the air and water is aided by the action of the roots of plants or trees, which help to force the rocks asunder. The exposed surface of a bed of rock is in this way gradually broken up into a mixture of decayed and partially decayed rock fragments. This layer forms the subsoil; it is covered by a layer of material still more thoroughly decayed by the continued action of the same agents, and by that of various animals, such as worms, which swallow the earth and eject it at the mouth of their burrows as worm castings. In some arid regions, where the soil is too dry for worms, their place is taken by white ants and other insects. Worms and other burrowing animals help to loosen the soil, and they add to it vegetable matter carried beneath the surface to line their burrows or for food; they thus contribute the organic constituents, to which most soils owe their fertility. Soils formed by the disintegration of the solid rocks immediately below them are called Sedentary Soils. Those formed from the decay of sheets of surface materials that have been deposited over the solid rocks are called Transported Soils.

Talus or Screes.—In mountainous countries rocks fall from cliffs, and form an accumulation of angular broken fragments at their feet. These accumulations are known as screes, or talus banks. If the slope of the scree is steep, then, under the influence of rain and wind, of burrowing animals, and slight movements due to rock expansion by heating during the day and contraction by cooling at night, the material creeps gradually downward into the valley.

Dunes.—The wind blowing across level country sweeps the loose material before it, and may pile it up, where it is caught by some obstacle, or perhaps by damp ground, into a line of hills known as dunes. They are usually composed of sand, because the lighter particles are blown further away, until they fall into some protected hollow or into water. The wind, striking the exposed side of a dune, drives the particles of sand slowly up the slope, and as they are rolled over against one another, they are often rounded and polished like microscopic marbles. The sand grains travel upward until they reach the crest of the dune, whence they fall down the lee side. By this process, sand is continually carried from the one side of the dune to the other, so that the dune slowly moves forward in the direction of the prevalent wind. They may gradually cover fertile land, burying trees or buildings by their advance. The movement of the dune may be stopped by planting it with some kinds of grass, the roots of which bind the sand together. If the dune cannot be thus checked, it may invade and desolate a populous district.

Loess.—Fine particles of clay are carried far afield by the wind, and may fall upon pools of water, or lakes, or on the sea, and therein be deposited as mud. But if the wind gradually loses its force, as it travels across a wide plain, then the clay may be deposited on the surface of the land. It is there usually mixed with grains of sand, and thus forms a sheet of loam. Many of the particles in this deposit will occur standing on edge, like cards that have fallen through the air on to a sheet of mud, and the number of vertical grains will be increased by roots forcing their way downward, and by the fragments being tilted as they fall through the blades of grass or branches of other plants. The particles in this wind-deposited loam will therefore be very irregularly arranged, and be interlocked like a felt. Hence it will break as readily in a vertical as in a horizontal plane, and though the material is soft, it may stand in vertical walls or faces. This material is known as loess. It occurs in thick sheets on former wind-swept plains. Advantage is often taken of its power of standing in vertical walls for the excavation of subterranean dwellings, as in China, Hungary, and Spain. The origin of loess as a wind deposit was first suggested from the nature of the fossil bones found in it, as they belonged to animals that live on treeless plains.

It is, however, probable that the material called loess in some districts is not a subaerial deposit.

AQUEOUS DEPOSITS

River Deposits.—Rivers transport sediment blown into them by the wind, or that is washed into them from their banks, or worn away from their bed. The distance sediment is carried depends upon its coarseness and weight, and on the velocity of the river. Grains of the heavy metals, such as gold or tin, soon fall on to the bed of even a rapid torrent; but fine particles of clay may be carried for a long distance and deposited when the speed of the current is checked by the river spreading out over a wider channel, or crossing a more level country, or entering a lake or the sea. The amount of material that a river can carry depends upon its velocity. The quicker the current, the more and the heavier the material it can carry. There is one particular speed for every part of every river at which it can just carry its burden of sediment without depositing any or picking up more from its bed or its banks. The river in that condition is said to have reached its *regime.* As a river does not then destroy its banks or block its channel by the formation of shoals, it is the object of engineers in charge of rivers or canals so to regulate the currents that they are in this condition of regime. But rivers that are not artificially controlled are subject to constantly changing influences; they are continually at work, denuding here and depositing there, and ever tending to shift the position of the channel.

River Fans.—When a mountain torrent escapes from a gorge or glen into a wider valley, the speed of the current is reduced and the coarse boulders and pebbles, which are rolled down its mountain bed, are piled up in a bank or fan-shaped heap at the mouth of the glen: thus the "river fan" may grow out across the wider valley as a huge embankment that is constantly increased in length by the addition of fresh material.

Deltas.—When a river enters a lake or the sea, its current is lost in the great body of still water;

hence the coarse material carried by the river is deposited around its mouth, while the finer material is carried further and spread in a sheet over the bed of the lake or sea. The material dropped at the mouth of the river at length forms a delta, which may be built up as a series of jetty-like processes on either side of the mouth, as in the Mississippi, or as a triangular sheet between different branches of the river, as in the delta of the Nile or of the Danube. A river fan may be compared to a delta which has been deposited on land instead of in water.

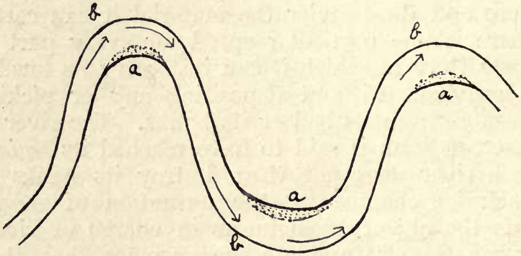

Fig. 13.

The Flow of a River Current in a Sinuous River. The stream is eroding its banks at *b*, and depositing material at *a*.

A river that flows across a level plain deposits the material that it has brought down from some higher part of its course in the deeper or broader reaches of the river, where the current is less powerful.

River action is complex, as it is not always either depositing or wearing away material at the same point. A heavy flood, due to a storm of rain, greatly increases the rate of flow and, therefore, the denuding power of the river; its bed and banks are worn away, and the material thus obtained is deposited when the flow of the river slackens on the abatement of the flood. A river, moreover, may deposit material on one side of its channel while wearing away its other bank. A winding river throws its current first against one bank, and then against the other; the current presses with most force against the bank on the outer side of a curve; the current is less rapid, or there may be an eddy with a flow upstream round the inner curve. Every one who has rowed upstream on a sinuous river knows that the current is strongest at the points *b* on Fig. 13, and weakest at the points *a*. In the dead water at the points *a*, the river may be depositing the material that it obtained by wearing away the bank at the point *b* further upstream.

A river crossing a plain may deposit sediment over the whole of its bed, while its banks are being raised by material caught by the vegetation growing along the water's edge. The whole channel of the river is thereby gradually raised, until, like some parts of a canal, it is above the level of the surrounding country (Fig. 14). A shoal forms, perhaps around a tree that has fallen into the river and been stranded on a shallow; material collects in the still water behind the obstacle and forms an islet. More silting takes place in the dead water below the islet, which may thus increase in size. This obstruction diverts the current against the bank, which is worn away and weakened, until the river bursts through and floods the surrounding country. The river may thus take up a new course, which it will raise and abandon as before. The repetition of this process, through the course of ages, forms a widespread plain of alluvium, through which the river winds its way. This level sheet is known as the "flood plain" of the river. The Nile furnishes a well-known illustration of a river which has raised its bed above the level of the surrounding country. When its level rises in the annual flood, the water pours over the banks and irrigates the adjacent lower country.

The material of flood plains is usually clay and loam, and their soil forms the rich river-side meadows. A river, however, that has only just emerged from rocky, hilly country may lay down a flood plain of shingle, through which the river flows in shallow, constantly changing, stony channels.

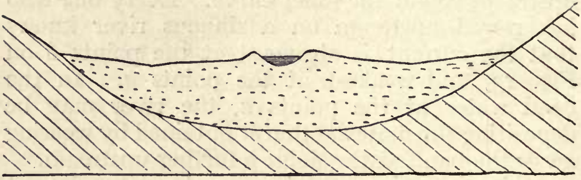

Fig. 14.

Section across a River Valley with the River raised above the Level of its Flood Plain.

Lacustrine Deposits.—Lakes act as great settling tanks, which collect all the materials carried into them by rivers. Thus the Rhone enters Lake Geneva as a turbid, muddy stream, which discolours the water of Lake Geneva for miles from its mouth; but all the mud settles in the lake, and the Rhone flows out of the lake at Geneva as a river of pure, transparent water. The material spread over lake-beds is usually fine grained, since all the coarser material is deposited in the deltas at the mouths of the rivers. Great lakes, like those of North America, are subject to storms, and the heavy waves falling upon the shore grind the rock fragments lying there into shingle. But lakes are not subject to strong tides like the oceans; their beach material is not swept backward and forward by the unceasing ebb and flow of the tide, so that it is more angular than that along a sea-shore.

Marine Deposits.—Deposits formed in the sea are of four main types. Along the shore, the battering action of the waves, and the constant backward and forward wash of the tide, grinds the fallen materials into beds of shingle and sand. The prevalent deposits in estuaries and off the mouths of rivers are formed of clay brought down by the rivers from the land. If some fine clay be stirred up in a pailful of water, the water will remain discoloured for some hours; but the addition of a spoonful of alum clears the water at once, by causing all the clay particles to fall to the bottom of the pail. Sea salt has a similar action, though the effect is slower. Hence, as soon as mud passes from the fresh water of a river into the salt water of the sea, the material is quickly deposited by this precipitating effect of sea salt.

Further from the shore the sea bed is covered with a mixture of sand and clay, and the shells and skeletons of the various marine organisms. The bulk of this material is sediment derived from the wearing away of the land. This material extends for some distance from the coast over slopes which lead from the shallow sea near the continents to the deep ocean floors. These beds are, therefore, described as the "deposits of the continental slope." Further from the land there is naturally much less sediment in the sea water, and in the centre of the great oceans much of the material deposited on the ocean floor consists of organic remains mixed with volcanic dust. These deposits are usually a soft, grey powder, known as ooze, which is sometimes formed of the shells of animals (Foraminifera and Radiolaria), and sometimes of those of minute plants, the diatoms. The material of " the great grey level plains of ooze, where the shell-burr'd cables creep," is deposited with extreme slowness. The deeper parts of the tropical oceans are covered by a widespread layer of red clay, the residue left after the washing out of all the soluble constituents of grey ooze.

Glacial Deposits.—In many parts of the temperate regions there are large areas covered by a confused series of deposits that have been laid down by the action of ice. When a glacier melts away, the mud and stones scattered through it are deposited as " moraines " around its edge, or as sheets of sand and gravel laid down by the streams from the melting ice. Outside the moraines that mark the former margin of the ice there are often widespread sheets of " boulder clay," composed of fine clay containing boulders that are generally scratched and grooved by ice action. The exact mode of formation of this boulder clay has given rise to prolonged controversy; but it must have been formed in positions whence the water produced from the melting of the ice could not drain off quickly, so that the light clay was not carried away. The sheets of boulder clay have probably been often formed in lakes due to the damming up of rivers by the ice, thus causing temporary ice-bound lakes. The beaches formed by such glacial lakes are well known in many places. The famous "Parallel Roads of Glen Roy" are the shore lines of a glacial lake that occupied part of Glen Spean and its tributaries near Ben Nevis; the different "roads" were formed at the successive levels of the water, as the lake was emptied by the melting of the glacier that blocked the outlet of the valley.

CHAPTER XII

THE ARRANGEMENT OF ROCKS IN THE FIELD

AFTER the student has become familiar with the characters of common rocks recognisable in hand specimens, he may proceed to the study of their arrangement in the field and see how large masses of these rocks build up the crust of the earth. The first apparent difficulty is that in many districts the rocks are scantily exposed to view. In mountainous countries there are ample exposures of the rocks in cliffs and crags, and in the beds of the streams that tumble down the hill-sides. On the coast, the rocks are generally well shown in long lines of cliffs. In more populous districts, however, and especially on plains, exposures of rocks are more difficult to find, and they are usually small and scattered. The surface of the country, when crossed by road, railway, or field path, may appear an unbroken expanse of meadow, field, or woodland. The beds and banks of the rivers may be formed of clay or sand, and there may be no waterfalls or cataracts exposing bars of rock across the river channels. But even in such districts some rock exposures can usually be found, and others are opened occasionally; and the local geologist has then the opportunity for useful work by studying them and describing their evidence. In populous districts brickfields afford sections in the clays and loams; quarries expose building-stone and limestone; sections in the road banks and the cuttings for railways show the harder rocks, and temporary excavations for drains or water-pipes show what rocks occur below the streets of cities. Mines, bore-holes, and wells often give sections deep below the surface. The evidence afforded by the plough and by material thrown out from rabbit burrows is also often useful.

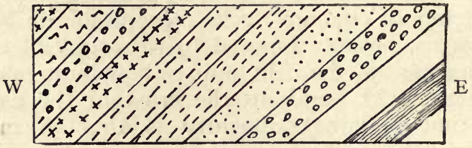

Fig. 15.
Inclined Strata dipping to the W.

It is convenient to consider first the arrangement of the stratified rocks, because they are the most widespread, and as they provide the time scale by which the age of the igneous rocks is determined. The stratified rocks are laid down in widespread layers that are usually deposited horizontally. Most stratified rocks are laid down on the floor of the sea or lakes, so that they are originally spread out in horizontal layers or beds. The surfaces between the successive layers are known as bedding planes, and they are usually conspicuous in any section of stratified rocks. A sandstone, when examined in a quarry, is usually found to have layers of different qualities, and may include seams of clay or conglomerate.

The bedding planes in rocks are not usually horizontal, for they have been tilted and have a well-defined slope. The angle between the slope of a bed and the horizontal plane is the "dip" of the bed. The amount of dip can be measured by a "clinometer," of which a simple form is a strip of wood bearing a semicircular card marked with angles. A plumb line or pointer is hung from the middle of the upper edge of the card, and swings freely over the graduated semicircle. When the long edge of the instrument is placed along a bedding plane in a quarry or cliff, the pointer will mark the number of degrees which the bed is inclined from the horizontal along that rock face; and this amount is the "apparent" dip, *i.e.* the dip in that one direction.

The dip, however, can be most conveniently measured on a sloping surface of rock. The clinometer can then be rested upon the surface and placed in the position at which the pointer rests furthest from the zero point on the card. The angle which the pointer then indicates is the greatest or "true" dip. A line drawn along the surface of the bed, at right angles to the direction of the clinometer, when showing the true dip, will be horizontal; and that horizontal line shows the "strike" of the bed.

The relation of dip and strike may be illustrated by a tilted card; the line having the steepest slope on the card is the line of true dip, and the dip can be measured along it by the clinometer. If the tilted card be dipped into a basin of water, the line along which the card meets the surface of the water is the line of strike.

The relation of dip and strike may be also illustrated by reference to the ridged roof of a house. The slates sloping down on either side represent the beds dipping in opposite directions, while the level crest of the ridge shows the course of the horizontal line—the strike. If a terrace of houses

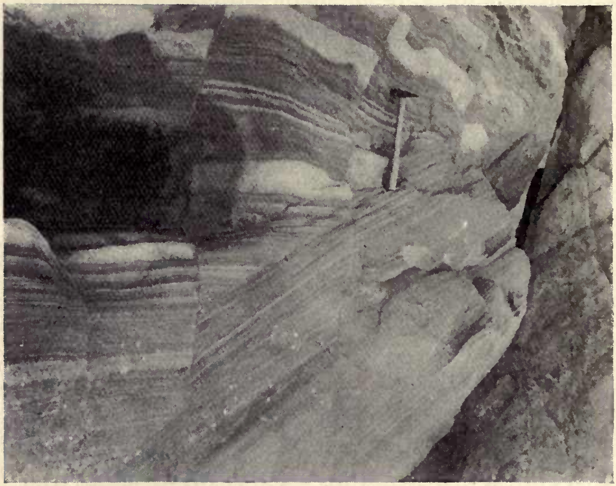

Fig. 16.

A Faulted and False-bedded Sandstone on the shore of Arran. The dark area in the left upper corner is a pool of water. (*By J. W. Reoch.*)

run north and south, the strike is north and south and the dip is to east and west.

False and Current Bedding.—Many rocks have minor bedding planes in addition to the main series, and these minor planes are inclined to the others, as they are due to the beds having been laid down on sloping surfaces. As this bedding was not laid horizontally, it is known as false bedding. Materials laid down upon steep slopes, such as the sides of valleys or along steep shores, will have their bedding parallel to the sloping surface upon which they are laid down. This original slope of the bed, given it during its deposition, must be clearly distinguished from the slope given to bedding planes by subsequent tilting. True bedding is always originally horizontal.

If successive layers of sand and clay be sprinkled over an ordinary basin, the layers on the flat bottom of the basin will have their bedding horizontal, while the layers on the sloping sides will be deposited with a false bedding (Fig. 17).

Sands laid down in a tidal estuary may have a very confused bedding, as the materials are laid down sloping in different directions owing to the rapid changing of the currents. Such irregular stratification is known as current bedding. There is, as a rule, no difficulty in distinguishing these irregular types of bedding from true bedding.

Unconformity.—All the beds exposed in a quarry or sea cliff may occur regularly one upon another, like a pile of books laid flat upon a table. If so, the beds are said to be conformable to one another, and they were laid down as a continuous series. Sometimes, however, the beds in one section belong to two series; the lower series may have a steep dip, and it may be covered by a series of horizontal beds. The relation between the two series is like that between books laid across the top edges of other books standing vertically on a shelf. In such a case the two series of beds are unconformable to one another. An unconformity indicates that after the deposition of the beds of the first series, they were tilted and worn away until a level or nearly level surface was again established. Then a new series of deposits was laid upon their worn, upturned edges. An unconformity shows that a considerable lapse of time has intervened between the deposition of the two series.

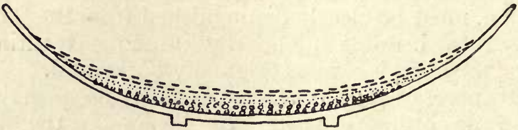

Fig. 17.
Section through a Basin, on which has been spread Layers of Coarse Sand, Fine Sand, and Clay. The layers on the middle are horizontal, those on the sides have a false bedding.

Joints.—The bedding planes of a rock are often crossed by a double series of cracks, by which a bed of rock is broken into separate blocks. These cracks are known as "joints," and their existence is of great value in quarrying. Joints are due to the shrinkage of the rocks after their formation. Most stratified rocks, when first deposited, contain

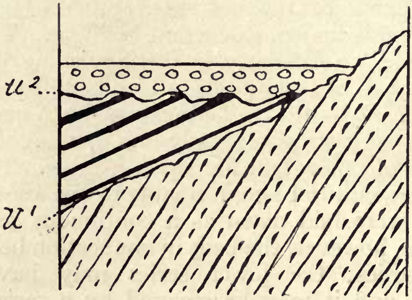

Fig. 18.
Section of a Quarry showing a Double Unconformity, at u^1 and u^2.

some water. As this water is gradually removed the material shrinks, and the cracks caused by the shrinkage are the joints. They are due to the same process as the cracks in mud on the floor of a dried pool, and as the columnar form of starch when starch paste slowly dries. Stratified rocks and thick sheets of igneous rocks are usually broken, by jointing, into rectangular blocks, but

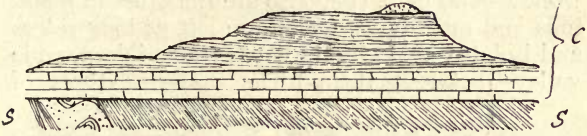

Fig. 19.

A Section through Ingleboro, in the Pennines. The Carboniferous beds (*c*) are resting unconformably on the Silurian beds (*s*).

when sheets of lava shrink by quick cooling, the jointing often forms long six-sided columns. These columns are beautifully shown in basalt, as in the well-known cases of Fingal's Cave in Staffa, and the Giant's Causeway in Ireland. (See also Fig. 26.)

Weathering sometimes produces a variety of jointing that breaks rocks into rounded masses, from which the surface peels off in concentric crusts like the layers of an onion.

CHAPTER XIII

THE DISTURBANCES IN THE ROCKS OF THE CRUST

The most familiar features of the earth's surface—its plains, valleys, and lakes—are due to ordinary geographical agencies that we can see in constant work around us. They also are the cause of many hills and mountains, which are left as long ridges and isolated peaks by the excavation of deep, wide valleys between them. The major features of the earth's surface are, however, not due to the surface agencies. Wind, rain, and weather, rivers, and sea affect only a very shallow zone. Their influence is like that of the sandpaper or the final chiselling with which a sculptor finishes off a piece of statuary. The bolder features of the earth's surface are due to deep-seated forces. The ocean basins have been sunk and continental masses raised by movements due to changes in the interior of the earth. When an apple dries it shrivels up, and the skin is accordingly thrown into a series of wrinkles; and if part of the apple becomes rotten, the skin over it will sink in.

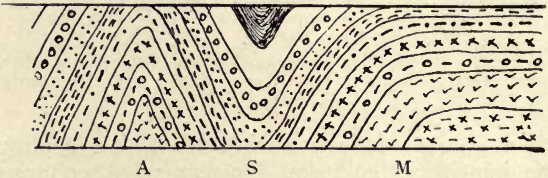

Fig. 20.

Folded Strata. A, Anticline; S, Syncline; M, Monocline.

Similarly with the earth. Geological evidence indicates that the internal mass is being slowly reduced in size; but the outer crust does not shrink at the same rate, and as it sinks it is compressed into a smaller space. The compression throws the crust into folds, as a cloth is wrinkled if it be pushed sideways across a table.

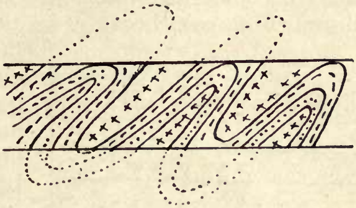

Fig. 21.
Isoclinal Folds.

Folds.—The dip of rocks is caused by a tilting, which may be due to the sinking of a tract of country, or to the earth's crust being compressed laterally, owing to the shrinkage in the size of the earth. If a piece of elastic be stretched and attached by its two ends beneath a sheet of cloth, and then the elastic be allowed to contract, the cloth will be thrown into a series of folds. This experiment illustrates the condition of the earth's crust. It is being constantly pressed into a smaller space owing to the shrinkage of the internal mass of the earth, and like the sheet of cloth, it yields

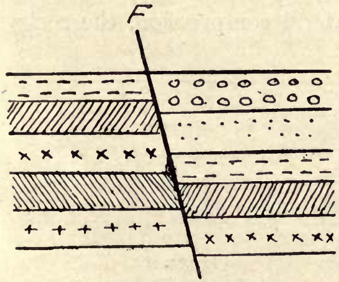

Fig. 22.
A Normal Fault. The downthrow side is on the right.

to the compression by being bent into folds. Each complete fold consists of a ridge and a trough. The ridge-like folds are known as anticlines (Fig. 20), because in them the beds are dipping away on either side from the central line. An anticline is indicated on a geological map by the symbol ←|→. The trough-like down-folds are known as synclines (Fig. 20), because the beds dip on either side towards the central line; the geological sign for a syncline is →|←. In mountainous countries, where the rocks have undergone extreme lateral compression, the rocks are bent into very crowded folds, and both sides of an anticline or a syncline may dip in the same direction as in Fig. 21. Such folds are known as isoclines. A fold produced by the sinking of part of a country, so that part of a sheet of rock remains at its original level, is known as a monocline (Fig. 20), as it is a fold with only one side. If an area has been uplifted at one point, the rocks are bent into a dome, and the beds dip in all directions from its summit. The corresponding structure produced by depres-

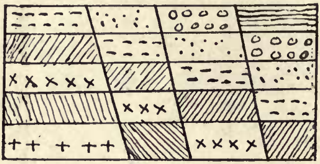

Fig. 23.
Three Step Faults.

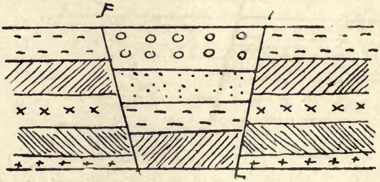

Fig. 24.
A Trough Fault.

sion around a point is a basin, where the beds all dip towards the centre.

Faults.—The continuity of a bed may be broken by a part of it having slipped downward along a fracture; this break in continuity is known as a fault. In a simple fault the beds on one side have slid downward along the fracture or fault plane, which is usually filled with crushed material known as "fault rock." The rocks on each side of the fault are often scratched and polished. The side of the fault on which the beds occur at the lower level is said to be the downthrow side of the fault, while the other is called the upthrow side. Several parallel faults with the downthrow always on the same side of the fault form a series of step faults. Parallel faults with a downthrow between them form a trough fault, and the valley between them is a rift valley. Parallel faults which leave a block of rock upstanding between two areas which have subsided are ridge faults, and the block between them is a "horst."

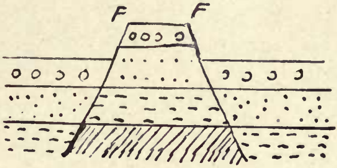

Fig. 25.
A Ridge Fault.

Fig. 26.—A Sill of Igneous Rock intruded into Sandstones on the Shore of Arran. The sill has been divided by joint-planes into short columnar blocks. (*By J. W. Reoch.*)

Fig. 27.—A more distant view of the same Sill, which is a branch from the Dyke seen in the foreground. (*By J. W. Reoch.*)

CHAPTER XIV

VOLCANOES, EARTHQUAKES, AND EARTH MOVEMENTS

THE sinking of the earth's crust as it follows the shrinking interior causes many disturbances in the stratified rocks, which may be still further altered by masses of hot molten material being forced into them. The sinking of the crust exerts intense pressure on the underlying area, and the hot rock beneath flows from these areas into those less strongly compressed. If the molten rocks consolidate at a considerable depth below the earth's surface and in vast masses, they form plutonic rocks, which often occur in blocks hundreds of square miles in area. A plutonic rock bakes and alters the rocks with which it comes into contact, changing them into rocks of the metamorphic group. Plutonic masses are, therefore, often surrounded by a circle of altered rocks, known as the contact aureole.

The edge of the intrusive mass is often irregular, as it sends thick, tongue-like projections into the adjacent rocks. These tongues may continue as thin sheets which have forced their way along cracks or fault planes, in which they consolidate and form those sheets of igneous rocks known as dykes. The molten rock that fills these dykes frequently finds its way into the cracks formed around a sunken block of the earth's crust; and some of the molten rock may rise through these cracks to the surface of the earth and form a volcano.

Molten rocks generally contain water, and when they approach the surface the heated water escapes as steam. The expansion of the steam helps the uplift of the rock, and near the surface the steam escapes with such explosive violence that the rock is blown into small pieces. They, after a short course through the air, fall in a heap around the vent; in time they build up a circular hill, with a central cup-like hollow known as a crater. The channel up which the molten rock rises is a volcanic "pipe," the mouth of which is the volcanic "vent."

Volcanoes were once regarded as burning mountains. It was thought that they were formed by the combustion of beds of coal melting the overlying rocks. The great dark cloud which rises from the volcano was regarded as smoke from the burning material, and the lurid glow at night was ascribed to flames. This appearance of smoke is due, however, to the presence in the steam of fine particles of volcanic rock—volcanic dust. The glow is the reflection on the clouds of the molten rock in the crater, which illuminates the clouds as the steam from a locomotive is lighted up at night when the fire-box of the engine is opened.

As the cracks which enable the volcanic material to reach the surface are often the results of earth movements, it is usual to find volcanoes around the edges of sunken areas. Thus Vesuvius, Etna, and the Lipari Islands occur beside that part of the Mediterranean known as the Tyrrhenian Sea, which occupies the site of a former extension of Italy that has foundered beneath the sea.

A volcanic hill may be built solely of fragments which have been shot up by explosions of steam—volcanic tuffs and agglomerates; or of molten rock—the lava—which has overflowed from the vent; or of mixtures of lava and tuff.

As the forces below the volcano lose power by the eruption of the surplus material, the pipe is closed by the solidification of the rock in it. The lava plug there formed prevents more material reaching the crater. Any further supplies of molten rocks are, therefore, unable to escape up the old channel, and are forced into cracks beside it; they often form radial dykes cutting through the volcanic hill. After the volcano has been much denuded, the dykes stand up as vertical walls by the washing away of the softer beds of tuff. The last trace of a former volcano may be the plug of hard lava that closed the vent, and is known as a volcanic neck.

There is no volcano in the British Isles with a still existing crater, but volcanic necks are common in many districts, as in southern Scotland and the Scottish Highlands. Snowdon, the highest of the Welsh mountains, is a volcano in the last stages of decay.

Earthquakes and Earth Movements.—The earth may be regarded as a great projectile travelling through space and spinning around its axis; and it consists of a hard, stony crust resting upon a more mobile interior, which is probably slowly contracting. If we watch a rapidly-revolving fly-wheel, we may see that it is constantly quivering. The earth's crust is also in a state of continual quivering owing to its high speed of rotation and its irregular composition. The surface of the earth at the equator is moving, owing to its rotation, at the rate of 1000 miles an hour; and the whirling crust is built up of masses of various materials having different strengths; it has a rough, irregular surface, and the distribution of weight upon it is constantly altering. Thus the weight of an inch of rain is 60,000 tons per square mile. Hence a heavy storm of rain over a large tract of country adds a great additional load to that part of the crust; and a heavy burden on one side of the earth, without anything to balance it on the other, would give the earth a slight tendency to wobble like a badly-balanced peg-top.

The crust of the earth is also disturbed by the attraction of the moon and the sun. Their attraction on the water of the sea causes its rise and fall, in the movement known as the tides; and the same force has a slight, but, as has been recently found, a perceptible, effect upon the crust of the earth, which rises and falls twice a day like the tide.

Under these various influences the whole crust of the earth is quivering like a fly-wheel. These small tremblings of the earth's crust are known as earth tremors.

In addition to these slight movements, which are perceptible only to very delicately-mounted instruments, the earth's crust is shaken by violent movements known as earthquakes, which often have disastrous effects.

One chief cause of earthquakes is probably the sinking of the earth's crust, to keep pace with the shrinking of the interior. If the rim of a fly-wheel be broken, the pieces are flung outward; but if all the parts of a fly-wheel were being pulled toward the centre by elastic cords, then when the rim cracked the pieces would be drawn towards the centre until they were jammed in new positions. When any part of the earth's crust is unsupported owing to the shrinkage of the material beneath, it falls inward and sends a wave-like disturbance or earthquake through the adjacent part of the crust. The sharp jerk caused by an earthquake may overthrow buildings and destroy towns; it will fling rock masses down from cliffs, and thus form dams across streams, alter the courses of rivers, and form lakes. If the earthquake occur below the sea, it may cause a great wave which, rushing on the shore, may devastate the coast. As the earthquake passes outward from its place of origin, its strength gradually dies away, until it may be felt only as a slight shaking, shown by the ringing of delicately-hung bells, or by special earthquake-recording instruments.

In addition to earthquakes caused by the foundering of blocks of the earth's crust, there are others due to raised masses of rock tending to slip toward any adjacent lower ground; many are caused by masses of material sliding down steep slopes on the edges of the continents, and others are due to volcanic explosions, which may be so powerful as to shake the whole earth. Thus the explosion of Mount Pelée in the West Indies in 1902 was felt in Melbourne eight hours afterwards as a wave-like movement of the surface.

Slow movements of the earth's crust cause the tilting of wide areas. Thus in recent geological times the region of the great lakes of North America has been tilted; the country to the south-west has remained stationary, while that to the north-east of Lake Huron, Lake Erie, and Lake Ontario has been elevated by an uplift, which increases to the north-east. This movement is shown by the lake terraces, which must have been horizontal when they were first formed, but which have now been tilted so that they slope downward from the north-east to the south-west.

PART IV

HISTORICAL GEOLOGY

CHAPTER XV

THE STUDY OF FOSSILS

THE branch of geology which deals with the former life of the earth is known as Palæontology, from the Greek words meaning "a discourse on ancient beings." Many rocks contain the remains of animals or plants that lived while the rocks were being deposited. Such remains are known as fossils; sometimes they are the actual skeletons, or shells, or stems; sometimes they are only traces of animals and plants, such as casts of shells, footprints, tracks made by animals that crawled over soft mud, or the imprints of leaves. The careful study of all these varied fossil remains has three principal purposes: (1) It gives the geologist the best means for comparing the ages of rocks in distant parts of the world. Rocks which contain the same kinds of fossils were formed at about the same period. Thus the limestones at Wenlock in the English Midlands, in the valley of the Yarra in Australia, and in the state of New York, all contain similar fossil shells and corals; hence the geologist knows that these limestones were all formed at the same time. (2) From the fossils of the different rocks in a district the geologist learns which of the rocks is the older and which the younger; thereby he determines the succession and distribution of rocks and the geological structure of the district. (3) Fossils reveal to us the history of life upon the earth.

The study of fossils reveals to a geologist the age at which a rock was formed, as an antiquarian learns from medals the dates of ancient ruins. It was the discovery, by William Smith (1769-1839), that fossils can be thus used as the "Medals of Creation" that gained for him the title of "Father of Geology" and founded modern geology.

Smith was a land surveyor working in the neighbourhood of Bath. The country in that part of England consists of a succession of limestone hills, trending roughly N.E. and S.W. and separated by valleys, the floors of which are beds of clay. One possible explanation of this arrangement might have been that the clays exposed in the valleys all belonged to one continuous sheet that formed the foundation of the whole country; and that the limestones were the remains of one overlying sheet that had been broken up into successive bands by the formation of the valleys. This interpretation is illustrated by Fig. 28. William Smith, however, discovered that, although the clays of the various localities are much alike in their general appearance, each band, L, F, O, and K, contains a quite distinct assemblage of fossils. Each of the limestones of the hills, I, G, and C, has also a different set of fossils, differing from one another, and from those in each of the clay bands. Smith, therefore, recognised that the country is built of seven beds instead of two; there are four beds of clay of different ages, separated by three beds of limestone. The structure of the country is as represented in Fig. 29, and not as in Fig. 28.

The beds are all tilted so that they sink eastward; hence a bore put down at K would go through all the beds of this series. The bed L was the oldest member of the series, and the other beds had been laid down one after another over it, in accordance with the first principle of historical geology, viz. that in a succession of deposits the oldest occurs at the bottom. Smith subsequently studied the country to the north-east of this area in the English Midlands. There he found that crossing the country from west to east the series begins with a sheet of clay containing the same fossils that he had found in the lowest and most western bed L in the series near Bath. This bed, the Lias, was not followed to the east by the limestone I and the clay F, but by a series of bands containing few fossils, and these, as a rule, different from those of I and F. Further east, however, there was another sheet of clay containing the same fossils as the bed O to the east of Bath. This clay was succeeded by a bed of limestone containing the same fossils as C, and that by clay with fossils of the bed K. Still further northward, in the district of the Wash (Fig. 31), the beds of clay, O and K, are well developed, but the limestone C is not found here, so that the two clays, distinct in themselves, form one thick bed. The western part of this bed can be recognised as the continuation of bed O, and the eastern part as the bed K, as when pits are dug in them they yield the particular fossils of these two clays. Still further north, in

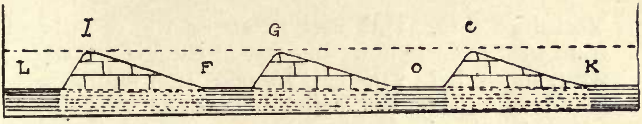

Fig. 28.

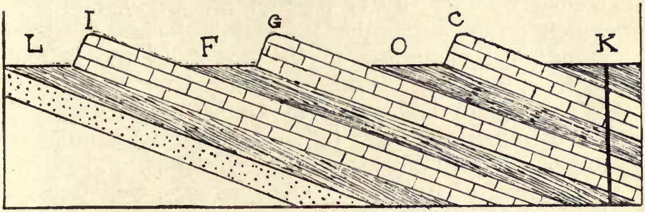

Fig. 29.

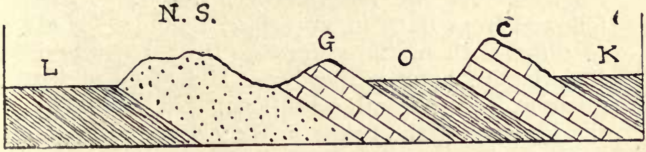

Fig. 30.

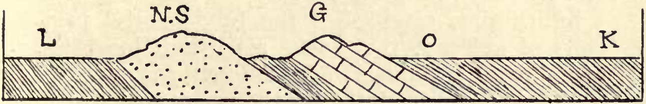

Fig. 31.

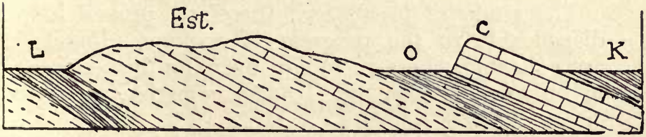

Fig. 32.

Diagrammatic Sections across the Jurassic Rocks of England, illustrating Wm. Smith's discovery of Correlation by Fossils. L, Lias; I, Inferior Oolite Limestones; F, Fuller's Earth; G, Great Oolite Limestones (with included sandstones and clays); O, Oxford Clay; C, Corallian Limestone series; K, Kimmeridge Clay; N. S., Northampton Sands; Est., Estuarine beds with some interstratified marine limestone.

Yorkshire (Fig. 32), a section across the country from west to east shows the clay of the Lias to the west, succeeded to the east by beds that had been laid down in estuaries, with an occasional thin bed of marine limestone. The estuarine series is succeeded by the clay O (the Oxford Clay), above which occurs an important series of coral limestones, corresponding to the bed C in the first section; and east, again, is the clay K.

The clays of the Lias (L), the Oxford Clay (O), and the Kimmeridge Clay (K), each contains similar fossils, alike in Yorkshire, the Midlands, and the south-west of England. The Lias was, therefore, being laid down at the same time all across England. As the beds between the clays are followed from Bath to Yorkshire, they are found to differ both in the nature of their rocks and their fossils, because they were laid down under different geographical conditions; but owing to the identity of the fossils in the clays, the intervening beds, whether marine or estuarine, can also be safely correlated.

Smith thus established the fundamental principle of geology, that rocks at distant localities, even though laid down under different geographical conditions, can be dated by the use of fossils.

The study of fossils has, therefore, proved indispensable to the progress of geology. Fossils are collected where rocks are open for inspection in railway cuttings, brick fields, quarries, mines, or sea cliffs.

Fossil animals are of more general importance to the geologist than fossil plants, for they are usually most abundant, and they give the best evidence as to the date of the fossil, and as to the geographical conditions and climate under which it lived.

The animals of most value to the geologist are those that have hard shells or skeletons, as those in which the body is composed only of soft materials seldom leave traces as fossils. The number of fossils is now so enormous that their description and full identification is usually left to specialists, who each confine their studies to one group. The geologist, however, should be able to recognise to which group a fossil belongs, as he can thereby often infer the geographical conditions under which the deposit was laid down and its approximate age. Fossils have to be first sorted into the chief subdivisions of the animal or of the vegetable kingdoms.

The animal kingdom is divided firstly into the two sub-kingdoms. In the first, the Protozoa, each animal is composed only of a single cell, or possibly of several similar cells. The animals belonging to the second sub-kingdom, the Metazoa, are always multicellular, that is, they are composed of many cells, and different cells are modified to do different work; one set of cells captures food, another set digests it, and another distributes it through the body; other cells serve as organs of sense, and others for locomotion.

The unicellular animals are generally so minute that they can only be seen, or their structure recognised, by the aid of the microscope; but they often live together in such great numbers that their dead shells form great masses of rock. Thus the Foraminifera (Fig. 33) usually build shells of carbonate of lime, which are littered over the sea floor, forming widespread deposits of ooze, or collected along the shore as beds of sand. If these deposits are cemented they form foraminiferal limestone, which often occurs in thick, widespread sheets. The Foraminifera contribute largely to the building up of chalk, and Nummulites, a gigantic member of the group, form the Nummulitic limestone, which extends around the Mediterranean basin and occurs at intervals across Southern Asia.

The second group of Protozoa important to the geologist is that of the Radiolaria (Fig. 34),

Fig. 33.
A Foraminifera (magnified).

Fig. 34.
A Helmet-shaped Radiolarian (greatly magnified).

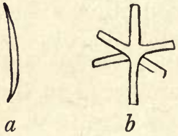

Fig. 35.
Sponge Spicules.
a. A Uniaxial Spicule.
b. A Six-rayed Spicule.

which have microscopic shells composed of silica. They therefore form siliceous ooze, which, when cemented into rock, forms beds of chert.

The Metazoa, or multicellular animals, are divided into two chief sections. In the first section, the Cœlenterata, the body consists essentially of a bag into which the mouth opens directly, and there is no separate digestive system. The Cœlenterates include the sponges, many of which have a skeleton composed of thin rods or spicules (Fig. 35) of silica, carbonate of lime, or a horny material, chitin. Sponges with siliceous or calcareous spicules contribute to the formation of siliceous rocks and limestone.

The second group of Cœlenterates is known as the Hydrozoa, since the most typical member is the common hydra that lives in pools and ditches. Hydrozoa are small individually, but they often live in large colonies, composed of very many individuals protected by a continuous skeleton. One section of Hydrozoa, the graptolites (Fig. 36), is allied to the sea-firs, which are common upon our coasts. Each graptolite is composed of a horny rod with one or more rows of cells along it; and in each cell lived a small hydra-like animal. Many graptolites sometimes grew from a central float. The graptolites are an extinct group, and were confined to the Lower Palæozoic period. They used to live floating in swarms on the surface of the sea. Some of the Hydrozoa have thick calcareous skeletons, and form one group of corals.

Fig. 36. The Lower Part of a simple Graptolite.

The ordinary corals, however, belong to the third group of Cœlenterates known as the Anthozoa, which includes the sea anemones and their allies. The ordinary corals agree in general structure with the sea anemones, but differ by having a calcareous skeleton. In some corals many individuals or polypes grow together in great masses forming reefs; these corals can only grow in warm water, so they are limited to shallow water in the tropical seas. Coral polypes that live separately and form single corals can live in colder waters, and are widely distributed in the sea, both in latitude and in depth.

The second section of the Metazoa forms the group known as the Cœlomata, because the body cavity or *cœlome* is separated from the tube, by which food passes into the body and is there digested. The Cœlomate animals are divided into those without and those with a backbone or vertebral column. Of the former there are four main divisions.

1. The Echinoderms, including the starfish, sea urchins or sea hedgehogs, the sea lilies, and sea cucumbers, all of which, except the sea cucumbers, have a well-developed skeleton. The sea lilies or crinoids are particularly important as limestone-forming animals.

2. The worms and their allies. Worms are usually soft bodied, but some of them live in hard tubes composed of carbonate of lime or of cemented sand grains; they either form calcareous rocks, or help to form cherts. Allied to the worms are two important groups of fossils, the Brachiopods or Lampshells, and Bryozoa. The former have a shell of two pieces or valves. Lampshells and their allies have lived from the earliest geological times to the present, but they are comparatively scarce in existing seas. They were formerly so abundant that their shells built up thick sheets of limestone, and they are especially useful in the correlation of the older rocks. Closely allied to the Lampshells are the Bryozoa, in which, though the individuals composing the colonies are minute, they form large encrusting sheets or moss-like growths, and their remains were once mistaken for fossil seaweeds.

3. The Arthropods, or animals with jointed limbs, include the water fleas, sand shrimps, wood lice, crabs and lobsters, centipedes, barnacles, spiders, mites, insects, etc. The shells of these animals are, as a rule, horny, and it is, therefore, only in special deposits that they are abundant

as fossils. The minute valves of the water fleas are often found in great abundance in mud laid down on the floor of lakes. The trilobites (Fig. 37) are an extinct class of Arthropods; they ranged throughout Palæozoic times. They had a body divided into three lobes, and some of them could roll themselves into a ball like a wood louse, to protect the soft gills on the under-side of the body. The Arthropods that live on land, such as scorpions, millipedes, centipedes, spiders, and insects, are comparatively scarce as fossils.

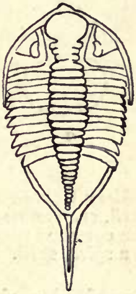

Fig. 37.
A Trilobite.

4. The Mollusca, including the shell-bearing animals commonly described as "shell-fish," is one of the groups of animals of most importance to the geologist, on account of the abundance and wide distribution of their fossil remains. The body of the mollusc is usually protected by a shell, which may consist of two pieces or valves, as in the common oyster, mussel, or cockle. Some molluscs, however, are protected by a shell of a single piece (hence its name "univalve") (Fig. 38); this shell may be a short cone, as in the limpet; or a long cylindrical or gradually tapering tube, as in the elephant's tooth shell (Dentalium); or a tube coiled into a disc, as in the common pond snail (Planorbis), or into a spiral, as in the turret shell (Turritella). In the univalve shells the tube may be open throughout its length, or it may be divided into many separate chambers, and if so, the animal that formed the shell lives in the last of them. The chambered tube may be straight, as in the Orthoceras, or coiled into a

disc, as in the nautilus and ammonite. Extreme modifications of the shell are found in the bone of the cuttle-fish or the guard of the belemnite, in which the chambered portion of the shell is reduced to a short cone in one end of a massive cylinder or guard (Fig. 39).

The backboned animals, or Vertebrata, have the body supported by a backbone that is composed of a chain of bony joints. The backboned animals are the fish, the amphibia—including frogs and newts—the reptiles, birds, and mammals. The backboned animals are the most specialised members of the animal kingdom, and they made their first appearance later in the earth's history than any large group of invertebrate animals. The fish are the most primitive of the backboned animals, and are naturally the oldest. They were first abundant in the Devonian period, which has been described as "the Age of Fish." Many of the earliest fish were protected by a bony external skeleton; of these fish with bony armour only a few now survive in lakes and rivers.

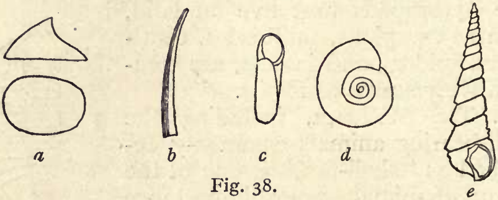

Fig. 38.

Four Univalve Shells. *a*, a simple conical shell; *b*, a tubular shell, such as the elephant's tooth shell; *c*, a coiled shell, such as the common pond shell, from the side; *d*, the same from above; *e*, a spiral shell.

The reptiles are most important in the Mesozoic age, which is therefore called "the Age of

Reptiles." They then dominated both land and sea, and included gigantic land animals estimated at about 100 feet in length; others that lived in the sea, and others that, by a wing-like development of the fore-limbs, as in the bat, flew in the air.

The mammals made their appearance at the beginning of the Mesozoic, but they remained insignificant until the beginning of the Cainozoic Era. Then the reptiles lost their supremacy, and the mammals increased in number, size, and variety, and they are the most highly developed and dominant of existing organisms.

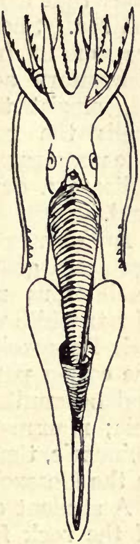

Fig. 39.
Restoration of a Belemnite. The part found fossil is the solid rod in the middle line of the lower part of the figure, in which it is half an inch in length.

The power to refer a fossil to its group is of great value to the geologist, as he may thus infer the conditions under which the rock containing it was formed. The presence of large massive corals shows that the rock must have been formed in a warm sea, and doubtless at a comparatively shallow depth. The occurrence of thin-shelled, single corals would, on the other hand, indicate that the rock had been formed in the sea, but in colder water and possibly at a great depth. The presence of Foraminifera and Radiolaria is proof of a marine origin, unless they have been washed into the rock from some older deposit. Sea lilies, starfish, sea urchins, large chambered shells, lampshells, or abundant Bryozoa are also indications that a bed containing them was formed in the sea. Shells may be formed on land, in the sea, or in fresh water; but a comparatively elementary acquaintance with Mollusca enables a geologist to infer from a few well-preserved shells the conditions under which they lived. The remains of insects, birds, or ordinary mammals indicate a deposit laid down either on or near land.

An elementary acquaintance with fossils also enables a geologist to tell the Group to which a fossiliferous rock belongs. Thus the discovery of a trilobite would prove that the rock containing it is Palæozoic; graptolites are clear evidence of the earlier part of the Palæozoic Era; ammonites and belemnites are almost confined to the Mesozoic; mammals or birds are characteristic of the Cainozoic, though their remains occasionally occur in the Mesozoic.

A student can use fossils to determine the age of the rock from which they came with greater precision if he will divide them into their different classes, and then identify them by comparison with those in a geological museum.

CHAPTER XVI

SUMMARY OF HISTORICAL GEOLOGY

THE history of the earth is read by the geologist from the rocks of the earth's crust, and according to their evidence geological time may be divided into four main divisions, known as Eras.[1] The first Era is often known as the Eozoic, because it was that of the dawn of life upon the earth. There is as yet no general agreement amongst geologists as to the classification of the rocks belonging to this most ancient Era; but the tendency appears to be to divide them into an older crystalline series, and a younger series of comparatively unaltered sediments. The crystalline or Archean series includes the oldest rocks that the geologist can collect in the field and study in his laboratory. All its rocks that remain to us have been subject to such intense heat that their constituents are chiefly crystalline, and they contain no recognisable remains of any life that may have existed on the earth at the time of their deposition.

The upper Eozoic sedimentary rocks have yielded a few obscure fossil remains. Most of the rocks are sandstones, shales, and slates, which have not been profoundly altered by heat; it

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[1] The International Geological Congress has recommended the following terms for the divisions of the stratified rocks and their time equivalents—

Group	is equivalent to	Era
System	,,	Period
Series	,,	Epoch
Stage	,,	Age

Thus the Silurian System is a member of the Palæozoic Group, and was deposited in the Silurian Period. Used technically these terms begin with a capital letter.

includes a vast series of comparatively unaltered sediments, intermediate between the Palæozoic and the Archean schists and gneisses.

The second great Era is known as the Palæozoic, or the Era of ancient life, for its rocks contain remains of the oldest and most primitive animals and plants of which we have any satisfactory information.

The third Era is the Mesozoic, or the Era of middle life. The fourth is the Cainozoic, or the Era of modern life, during which the earth was inhabited by animals of modern types, some of which were the near ancestors of those still living; it is conveniently regarded as including the present time, though geological history ends with the beginning of the records written by man.

The Archean rocks may be divided into two chief divisions. The lower rocks are in the main coarsely crystalline, and they include a complex series of gneisses, schists, and igneous rocks. The upper division consists of fine-grained gneisses and schists, and of quartzites and crystalline limestones; their arrangement in the field resembles that of an ordinary stratified series. As the coarsely crystalline rocks lie below the less crystalline, they were naturally at first regarded as the older; but they have been proved in some cases to be intrusive rocks forced into the overlying series, and are, therefore, the younger in age. The rocks of the upper or less crystalline division are principally, no doubt, a series of sedimentary rocks that have been metamorphosed. The Archean rocks in several parts of the world occur in vast areas, covering hundreds of thousands of square miles. There are some less extensive schists that were formed in post-Archean times, but no schists constituting wide regions have yet been proved to have been formed in a time later than the Archean.

Above the crystalline rocks of the Eozoic Group is a thick series of sedimentary rocks, mainly conglomerates, sandstones, and shales, which are often no more altered than many sandstones of much later dates.[1] They are, however, practically barren of fossils, and are, therefore, often included in the Archean. Some of the Scottish sandstones of this Group were once regarded as belonging to the much younger Old Red Sandstone (p. 121). These rocks are so little altered that if animals with hard shells had lived during their deposition, there is no reason that fossils should not have been preserved. Hitherto, however, these rocks have proved almost unfossiliferous. The world was not uninhabited during their deposition; for they yield occasional fossils, such as Beltina, a crustacean found in Montana; and the Torridon Sandstones of Scotland include phosphatic grains which retain traces of organic structure.

The Archean limestones may have been formed by some living agency, and the Archean graphite and hydrocarbons may be the last stage in the alteration of some seaweeds. We are, however, still without any but the scantiest knowledge of life before the Palæozoic Era. It is probable that most of the creatures living before that date had no shells or hard skeletons. and thus left no direct traces of their existence,

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[1] These rocks in America are included in the Algonkian System, and that term has been used for the equivalent rocks in some parts of Europe. They are represented in the British Isles by the Torridon Sandstone of north-western Scotland.

The Archean division is sometimes called the Azoic—that is, without life; but it is rather the period in which the animals were without shells.

The Palæozoic Group includes six Systems, all of which contain abundant fossil remains. The oldest of the Systems is the Cambrian, which was so named from its development in North Wales. Its rocks have yielded abundant fossils, including representatives of all the chief groups of the animal kingdom except the bone-bearing animals (the vertebrates); and the fact that so many distinct groups of animals were then in existence shows that life must have existed on the earth for a very long period previously.

The Cambrian rocks mostly consist of coarse sediments, laid down as shore deposits or in shallow seas. There were numerous volcanic eruptions during this period, and the rocks have been considerably altered by earth movements, so that the clays that were then formed have been pressed into slates. Limestones were not abundant, but they occur in some localities as in the north-west of Scotland. The most characteristic animals of this period were the trilobites, upon the succession of which the system is subdivided, and the various subdivisions correlated in different parts of the world.

The Ordovician System was named after the tribe of the Ordovices, who lived in Shropshire and along the Welsh border. The Ordovician Period was marked by intense volcanic activity beginning with great eruptions in the Lake District, while the sea covered southern Scotland and Wales. By the close of the period the volcanic centre had moved from the Lake District to North Wales, and the eruptions there discharged the mass of volcanic rocks that form the mountain of Snowdon. The characteristic fossils of the Ordovician rocks are graptolites.

The Silurian System was also named after a tribe that lived in the border country between England and Wales. The Silurian Period was characterised by the comparatively quiet deposition of sediments and limestones in a widespread sea. Volcanic activity was practically dormant. The typical rocks of the Period are shales and limestones; and many of the English Silurian limestones are so rich in corals that they must have been formed as coral reefs in a warm sea. The life of this Period marks a great advance upon that of the two earlier Periods; and it includes the oldest known insects and fish, which are the first representatives of the back-boned animals.

The Devonian.—The Silurian System was brought to a close by its shales and limestones gradually giving place to coarse sediments that must have been formed either along the shore, or on land, or in fresh water; and this change was due to an emergence of the land from the sea. A continent was thus formed in the Devonian Period, and it occupied the northern part of the North Atlantic and included all Europe north of a line across southern Ireland, along the Bristol Channel, and the valley of the Thames, and thence across Belgium and Germany to the Gulf of Finland in Russia. This continent extended so far northward as to include Spitsbergen. The chief deposits formed upon this land were the thick series of sandstones known as the Old Red Sandstone. South of this land lay a sea wherein was deposited a series of marine rocks, which were first recognised in Devonshire, and so the System has been named the Devonian. The Devonian marine rocks were formed at the same time as the Old Red Sandstone. The earth movements which upraised the Devonian land were continued through the Period, and were accompanied by volcanic eruptions that piled up huge volcanic domes in Scotland; and there were many volcanic islands, the shores of which were fringed with coral reefs, in the sea covering southern Devonshire. The sea and fresh waters then swarmed with large fish, the most characteristic of which were protected externally by an armour of plates of bone. As the fish were the dominant forms of life, the Devonian Period is often called " the Age of Fish."

Carboniferous.—The Devonian Period was followed by the Carboniferous, and the change was marked by a submergence of England, Wales, and Ireland, by a great extension of the sea. A thick limestone—the Carboniferous Limestone—crowded with corals, sea-lilies, and other fossils that indicate a clear, open sea, was deposited on its bed. The sea sometimes extended into southern Scotland, which for most of the time stood above sea level, with occasional submergences beneath a shallow sea. Thus, while the rocks of the lower part of the Carboniferous System in the south of England include a sheet of limestone some thousands of feet thick, they consist in Scotland of volcanic rocks, thin beds of limestone, sandstones, and clays. There are also, in the lower Carboniferous rocks of Scotland, seams of coal, some of which may have been formed as a forest growth on land, as the sites of some ancient forests are found in these rocks.

The great depression which led to the formation of the Carboniferous Limestone in England was followed by an uplift which converted the whole of the British Isles into land. Great forests grew on this land, and some of their vegetation has been preserved as the coal seams, which are the most important source of British mineral wealth. Some of the coal may have been formed in swamps and lakes, but some of it was certainly formed on the sites of forests, as the roots of trees are still found in the clay beneath the coal seams.

The Carboniferous Period in the British Isles appears to have had a somewhat warmer and moister climate than the present, judging by the great development of corals in the Carboniferous limestone sea, and the luxuriance of the vegetation in the Coal Measure forests. In the southern hemisphere, on the other hand, the climate may have been colder than at present. In the Carboniferous, Permian, and some later periods a vast continent extended from eastern Brazil to Australia, including southern Africa, the Indian Ocean, and southern India. It is called Gondwanaland, from the Gondwana beds of India. Some of the mountains of this continent were capped by perpetual snow, and great glaciers flowed down from them on to the lowlands. There is no direct evidence that the ice then reached the sea in Africa or India, but icebergs at this date floated in the sea further north than Sydney in eastern Australia, and in West Australia glacial beds were laid down interstratified with marine deposits. The climate of Gondwanaland was, therefore apparently colder than that of the existing fragments of that continent, though there is no evidence of cold conditions in Europe at the time when these glaciers existed in southern Africa, India, and Australia.

The Permian.—The Carboniferous Period was followed by a time of great earth movement and volcanic activity, during which a range of mountains (the Armorican-Variscan chain) was raised across central Europe, extending from the south of Ireland and Brittany eastward into Germany.

In addition to the folds that formed the eastern and western chain, a series of movements along faults that ran north and south uplifted and tilted great blocks of the crust, and thus formed the Pennine Range. These combined earth movements enclosed an inland sea that extended from Germany into northern England. In this sea were laid down thick beds of dolomitic limestones, red shales, and red sandstones. The animals that lived in the sea of this period were mainly stunted survivors from the rich Carboniferous fauna; but the steady progress in the evolution of life with the advance of time was marked by the varied forms of reptiles and amphibians that lived both on land and in water in the Permian Period.

The Mesozoic

The Permian was the last System belonging to the Palæozoic, and its successor, the Trias, was the first of the three Systems of the Mesozoic—the middle Era in the history of life on the earth.

The Trias.—The Permian movements had converted most of northern Europe into part of a great continent. The most characteristic deposits laid down on this land were sheets of red shales and sandstones, grouped together as the New Red Sandstone. Arms of the sea were cut off in this land; their waters gradually evaporated and left the rich deposits of gypsum and rock salt which are now mined in Cheshire and Worcestershire, and supply most of the salt used in the British Isles. The formation of these beds of salt shows that the climate must have been very dry, as the evaporation would not have taken place in a rainy country. The south-west winds were then prevalent in the British Isles as at present. These winds now bring us most of our rain, so they must then have been dried before reaching the British area; they had probably lost their moisture by passing over land that extended far out into the Atlantic, and perhaps by crossing over the high mountains formed by the Permian movements.

The British Isles in the time of the New Red Sandstone were a desert, and, as shown in Leicestershire, its surface was carved by blown sand, showing forms due to wind erosion similar to those of existing deserts. In Germany somewhat the same conditions prevailed through most of the Triassic time, but they were interrupted by a temporary occupation of the country by sea. Further to the south, in eastern Switzerland and western Austria, all the Triassic rocks were formed in a sea that was the forerunner of the Mediterranean.

Fossils are usually scarce in the British New Red Sandstone, but there are footprints of great land animals, bones of crocodiles, and occasional shells of crustacea, such as water fleas, similar to those that live in pools or salt lakes in Central Australia. All the characteristic forms of

Palæozoic life had become extinct, more modern types appearing to take their place.

The Jurassic.—The Trias was followed by the Jurassic; in contrast to the Triassic, this was essentially a marine period. The sea submerged the land in a series of successive advances. The Jurassic System takes its name from the Jura Mountains, where these rocks are well developed. The English Jurassic rocks are marine limestones, sands, and clays. The limestones are often oolitic in structure (*see* p. 52), and furnish many of the most valuable of English building-stones. The first birds make their appearance in this period, and there are occasional remains of mammals; but this was especially "the Age of Reptiles," of which many then lived on land or in the sea, while some flew in the air. Some of the largest of these Jurassic reptiles lived in swamps, and were much longer than any existing land animals. The characteristic animals of the Jurassic seas were the ammonites and belemnites, two extinct groups, related respectively to the nautilus and cuttlefish. Another characteristic shell is that of the Trigonia, which became extinct in Europe at the close of the Mesozoic, but is still living in the seas of Australia.

The Cretaceous.—The Cretaceous System derives its name from the Latin word *creta*, chalk, its most characteristic rock. The Cretaceous System is divided into two well-marked divisions. It began in many areas with land conditions due to the uplift which brought the Jurassic Period to a close. The best known of these continental deposits in the British Isles occur in the Weald of Kent and Sussex. They were probably laid down on the shores of a great estuary, and the land was clad with forests of Cycads—trees allied to the ferns—and was the home of gigantic reptiles with a kangaroo-like gait, such as the iguanodon. The rocks of the upper part of the Cretaceous System were marine in origin. The Wealden land gradually sank below the sea, which was deepened and widened till in the time of the chalk it extended at least from Ireland, across Europe to the Crimea, and in it was laid down a limestone of exceptional purity. It contains so little sedimentary material that it must have been formed far from land. Some boulders found in the chalk near London were probably dropped there by icebergs, which had drifted southward and there melted away.

The Jurassic and Cretaceous Periods in the British Isles were free from volcanic eruptions; but the Cretaceous was brought to an end by great earth movements which raised the floor of the chalk sea into land, and these disturbances, in many parts of the world, culminated in prolonged and widespread volcanic activity.

THE CAINOZOIC

The interval between the top of the chalk and the deposition of the earliest beds of the Cainozoic must have been very prolonged: for such influential geographical changes happened in it, that the rich Mesozoic fauna found in the upper beds of the Cretaceous had all become extinct before the deposition of the lowest beds of the Cainozoic. New animals and plants made their appearance, and they were all of more modern types, marking the beginning of the Era of recent life.

The Eocene.—The Cainozoic is divided into five Systems, of which the lowest is known as the

Eocene or "the dawn of recent life." Its beds were formed partly in shallow seas or along coasts, and partly in lakes and on land. Marine deposits of this Period occur in the London and Hampshire basin, and include the London Clay, which forms the foundation of London. Further west, up the Thames Valley near Reading, and in Devonshire, in Ireland, and also in Scotland, the Eocene deposits were formed on land. A continent must have extended from western Scotland across the Atlantic towards Iceland and Greenland, and this great land began to be broken up by the subsidences that later on formed the basin of the North Atlantic. Great volcanoes burst into eruption around the sinking area, ejecting the first of the sheets and piles of lava that form some of the best-known features in the scenery of the Scottish Isles.

The Oligocene.—The Oligocene Period, which followed the Eocene, was mainly a continental formation, only one marine deposit of this age occurring among the fresh-water and land deposits then laid down in the British Isles. A great sea, the forerunner of the existing Mediterranean, covered much of southern Europe, extending eastward into Asia and westward to the West Indies. Northern and central France and Germany were then land, and pines in the Oligocene forests of Germany exuded a resin that has been since converted into amber.

The Miocene.—The Miocene—the Period of less recent life—in central and southern Europe has numerous marine rocks, but northern Europe was then occupied by land. This Period is most remarkable as a time of great mountain formation. Among other mountains then raised are the Alps and Alpine system of Europe, the Atlas in northern Africa, and the mountains of the Himalayan system in Asia. The climate of this period appears to have been somewhat warmer than at present, judging by the vegetation that then lived as far north as Greenland and Spitsbergen.

The Pliocene.—The Pliocene—the Period of more recent life—was characterised by a gradual increase in the coldness of the climate of north-western Europe. The chief deposits in this System in the British Isles are the shell beds known as the Crags of Suffolk and Norfolk. The lower beds of the series contain fossil shells belonging to genera not now living in the British seas, but which survive in the Mediterranean; these southern shells disappear from the later Pliocene beds, and their place is taken by Arctic shells, showing that the British seas were becoming colder.

Pleistocene.—The climate became still more severe in the early part of the succeeding Period—the Pleistocene—when the mountains of the northern and western parts of the British Isles were covered by perpetual snow. Glaciers flowed from the mountain snow-fields into the valleys and on to the plains; as the ice melted, these plains were covered with widespread sheets of glacial beds, and with sheets of clay, that had been deposited in lakes formed by ice-dammed rivers. The cold climate is not only proved by the nature of the deposits, with their ice-scratched stones, and by the ice-worn surfaces of the rocks, but also by the animals and plants whose remains are found associated with these deposits. Remains of the musk ox, which now lives in northern Greenland, in the northernmost parts of North America and in its adjacent islands; of the reindeer, which now inhabit only the colder regions of America and Europe; and of the hairy mammoth which, akin to the elephant but covered with thick hair, ceased its wanderings in northern Siberia—remains of all these have been found in the British glacial and post-glacial deposits. The plants found in the peat beds associated with the glacial beds include such far northern plants as the Arctic willow, and some that now live only at sea level in the Arctic regions or high up on the mountains of the British Isles and on the Alps. The occurrence of these plants in beds formed in the lowlands shows that the British climate was then much colder than at present.

The glacial conditions existed longer in Scotland than in England, which enjoyed a mild climate, while the Scottish mountains were still snow-covered, and glaciers flowed down the western valleys to the sea. The land of the British Isles was then part of the Continent; many English rivers, such as the Thames and those from the Wash and Humber, were tributaries to the Rhine, which was prolonged northward across the plain that is now the bed of the North Sea.

Such were the geographical conditions when man first entered the British area. It had a colder climate than at present, for glaciers still existed on the Scottish mountains. He wandered into the country overland from the Continent. That he was a contemporary of the mammoth and reindeer is proved by carvings found in some of the caves occupied by these early men. Reindeer horns with carved imitations of the reindeer, and sketches of the mammoth and reindeer engraved on fragments of mammoth tusk (Fig. 40), proved that the men who made them were acquainted with those animals.

The earliest inhabitants of what are now the British Isles had no domestic animals, and they did not know the use of metals. They lived only by the chase and fishing, and had implements of wood and bone which they shaped with tools made of chipped stone. Owing to the primitive character of their stone tools, these people are described as "Palæolithic"—that is, belonging to the older Stone Age. They did not live in Scotland, as the climate was probably then still too severe.

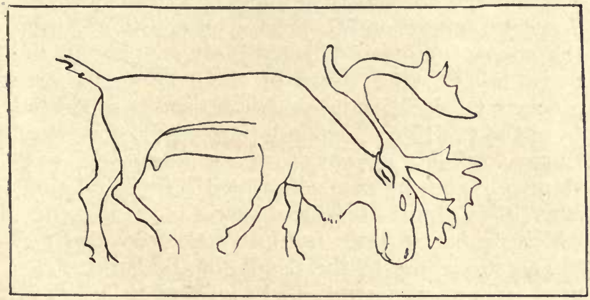

Fig. 40.

Sketch of a Reindeer, engraved on a piece of Mammoth tusk, by Palæolithic man. From the Kessler Loch, near Schaffhausen, Switzerland.

These people were succeeded by the Neolithic men, or those of the later Stone Age, who had discovered how to make much better stone tools by grinding their edges smooth and sharp. The climate had now become warmer throughout the British area, so that although a few Scottish glaciers still reached sea level, Neolithic man inhabited Scotland as well as England.

The Neolithic people were succeeded by races who could work in metal, and the next Age is known as the Bronze Age, because the metal tools which survive from it are mostly made of bronze. It is probable that iron implements were made earlier than those of bronze, but iron rusts away so readily that they have not survived. The people of the Bronze Age spread across Europe, and some of the most complete collections of their domestic articles and tools have been obtained from the sites of ancient villages built on piles in the Swiss lakes. One group of these Bronze people reached Great Britain, which was now separated from the Continent, around the coasts of western Europe. They appear to have been sun worshippers, and in connection with their religious rites they built temples such as Stonehenge, which probably dates from about 1800 years B.C.

The successors to the people of the Bronze Age used iron in preference to bronze, as it is a more serviceable metal and more abundant than the tin and copper of which bronze is made; and with the Iron Age the story of the earth, as far as concerns the British Isles, passes from the sphere of Geology to that of History.

GLOSSARY

Acid (Latin *acidus*, sour). This term is applied in geology to aqueous rocks containing a large proportion of silica.

Æolian (Greek *Aiolos*, god of the winds). Deposits formed on land by the action of the wind.

Algonkian (named after a tribe of North American Indians). The geological System that includes the sedimentary rocks, younger than the Archean and older than the Palæozoic.

Amphiboles (L. *amphibolum*, ambiguous, from the variable nature of the mineral). A group of minerals important as constituents of many rocks. Most of the species contain iron and magnesium. Hornblende is the typical species.

Andesite (named from the Andes, where it is abundant). A lava intermediate in composition between those rich in silica and those poor in silica.

Anticline (Gr. *anti*, on opposite sides, and *klino*, I bend). An archlike fold of stratified rocks.

Apatite (Gr. *apate*, deceit, and *lithos*, stone). A mineral species composed mainly of phosphate of lime.

Archean (Gr. *archaios*, ancient). The earliest subdivision of the Eozoic rocks.

Arenaceous (L. *arena*, a sand grain). Rocks composed of sand grains.

Argillaceous (from Gr. *argillos*, clay; L. *argilla*). Rocks and beds composed of clay.

Arthropods (Gr. *arthron*, a joint, and *podes*, feet). Animals with jointed limbs.

Augite (Gr. *auge*, lustre). The commonest mineral species belonging to the group of the pyroxenes.

Barysphere (Gr. *barus*, heavy, and *sphaira*, a sphere). The central mass of the earth, so named on account of its weight.

Basalt (word of African origin). Basic lava or dyke rock.

Base (Gr. *basis*, foundation). A material that combines with an acid without losing anything.

Basic. This term is applied in geology to igneous rocks rich in bases and containing a comparatively small proportion of silica.

Brachiopods (Gr. *brachion*, arm, and *podes*, feet). A class of marine animals with a shell composed of two valves; the body has a number of arm-like processes, whence the name.

Breccia (Italian, a breach in a wall). Rock composed of coarse angular fragments.

Bryozoa (Gr. *bruŏna*, mossy, and *zoon*, a living being). A class of compound animals usually growing in tufts or thin sheets.

Cainozoic (Gr. *kainos*, recent, and *zoe*, life). The Period of recent life—the name of the last of the four geological Eras.

Calcareous (L. adj. *calcarius*, from *calx*, lime). Composed of carbonate of lime.

Clastic (Gr. *klastos*, broken to pieces). Sedimentary rocks composed of fragments.

Cleavage (Gr. *klaō*, to break in pieces). The property of which some minerals or rocks break in with smooth flat surfaces.

Cœlenterata (Gr. *koilos*, hollow, and *entera*, entrails, guts). The group of multicellular animals in which there is no digestive cavity separated from a distinct body cavity.

Cœlomata (Gr. *koiloma*, a hollow cavity). The group of multicellular animals in which there is a digestive tube distinct from the body cavity.

Conglomerate (L. *conglomero*, I roll together). A rock composed of rounded pebbles.

Crinoid (Gr. *krinon*, a lily, and *eidos*, likeness). A sea lily. The Crinoidea are a class of Echinoderms.

Crystalline (Gr. *krustallos*, ice). Composed of crystals.

Diatoms (Gr. *dia*, through, and *tome*, a cut). A group of minute aquatic plants with siliceous shells, each of two valves.

Diorite (Gr. *dioros*, a well-marked distinction). The typical plutonic rock of the sub-basic group.

Dolerite (Gr. *doleros*, deceptive, and *lithos*, a stone). The basic igneous rock less coarse grained than gabbro.

Dolomite (named after a French mineralogist, Dolomieu). The mineral species or rock composed of approximately equal amounts of carbonate of lime and carbonate of magnesia.

Echinoderms (Gr. *echinos*, the sea urchin, and *derma*, a skin). A group of Cœlomate animals with spine-bearing skin or shell.

Eocene (Gr. *eos*, the dawn). The dawn of recent life, the first System of the Cainozoic.

Eozoic (Gr. *eos*, the dawn, and *zoon*, a living being). The Era of the dawn of life. The name of the oldest of the four geological Eras.

Felspars (from German *fels*, rock, and *spath*, a spar or mineral). A group of rock-forming minerals.

Felspathoid (from felspar, and Gr. *eidos*, likeness). A group of minerals that may replace the felspars in igneous rocks.

Femic (Fe, the symbol for iron (L. *ferrum*), and M stands for magnesium). A term applied to substances containing much iron and magnesium.

Foliation (L. *folium*, a leaf). The arrangement of the minerals in a crystalline rock in parallel layers.

Foraminifera (L. *foramen*, an opening, and *fero*, I bear).

Microscopic unicellular animals that live in the sea; their shells are important constituents of many limestones.

Gabbro (Italian). The typical basic plutonic rock.

Granite (It. *granito*). The typical acid plutonic rock.

Graptolite (Gr. *graptos*, marked with letters, and *lithos*, stone). An animal belonging to an extinct class, Hydrozoa.

Holocrystalline (Gr. *holos*, whole). A term applied to rocks wholly composed of crystalline constituents.

Hornblende (German *horn*, metal, and *blenden*, to deceive, because containing no metal, although of a metallic lustre). The chief mineral species of the group of the Amphiboles.

Hydrozoa (Gr. hydra, the water-snake, from *hudor*, water, and *zoon*, a living being). A class of Cœlenterate animals, including the hydra, the sea-firs, and the extinct graptolites.

Isocline (Gr. *isos*, equal, and *klino*, I bend). A fold in which both sides are inclined in the same direction.

Keratophyr (Gr. *kerata*, horns; *phyr* is adopted from the name "porphyry," which meant purple, and was given by the Greeks to a purple igneous rock). An acid igneous rock rich in soda or other alkali.

Leucite (Gr. *leukos*, white). A white-coloured mineral especially abundant in some Italian lavas.

Liparite (named from its abundance in the Lipari Islands). A lava rich in silica.

Lithosphere (Gr. *lithos*, stone, and *sphaira*, a sphere). The stony crust of the earth.

Magnetite. An oxide of iron with strong magnetic properties.

Merocrystalline (Gr. *meros*, a part). A term applied to rocks partly composed of crystalline constituents.

Mesozoic (Gr. *mesos*, middle, and *zoe*, life). The middle Era of life; the third of the four Eras into which geological time is divided.

Metamorphism (Gr. *meta*, after, as in physics and metaphysics; and *morphe*, form). A change in a rock which alters the arrangement of its materials, but not its composition.

Metasomatism (Gr. *meta*, after, and *sōma*, a body). A change in a rock which alters its composition.

Metazoa (Gr. *meta*, after, and *zoe*, life). The sub-kingdom of animals in which each animal is composed of many cells.

Mica (L. *mico*, I glitter). A group of mineral species characterised by breaking into thin glistening flakes.

Minerals.—The inorganic constituents of the earth's crust. Mineral species are minerals that cannot be broken up into other kinds of minerals by mechanical processes.

Miocene (Gr. *meion*, less, and *kainos*, recent). The middle Period of recent life; the middle Period of the Cainozoic Era.

Mollusca (L., meaning a soft nut with a thin shell, from *mollis*, soft). The group of animals including the "shell-fish."

Monocline (Gr. *monos*, single, and *klino*, I bend). A fold with only one side.

NEBULA (L., meaning a vapour, cloud). A star composed of either a cloud of gas or swarm of meteoritic masses.

NEPHELINE (Gr. *nephile*, a cloud). A mineral species found in some igneous rocks rich in soda.

OLIGOCENE (Gr. *oligos*, little, and *kainos*, recent). The second in time of the five Systems of the Cainozoic Group.

ORTHOCERAS (Gr. *orthos*, straight, and *keras*, a horn). A chambered shell like a straight, uncoiled nautilus.

PALÆOZOIC (Gr. *palaios*, ancient, and *zoe*, life). The Era of ancient life. The second of the four geological Groups and Eras.

PHONOLITE (Gr. *phonea*, sound, and *lithos*, stone). A lava rich in soda: it is used for rock harmonicons, hence its name.

PLEISTOCENE (Gr. *pleistos*, most, and *kainos*, recent). The last of the five Systems of the Cainozoic Group.

PLIOCENE (Gr. *pleion*, more, and *kainos*, recent). The fourth in time of the five Systems of the Cainozoic Group.

PLUTONIC (named after Pluto, the God of the infernal regions). The igneous rocks that have solidified deep below the surface of the earth.

PROTOZOA (Gr. *protos*, first, and *zoe*, life). The lowest group of the animal kingdom, including animals composed of only one cell, or of a few exactly similar cells.

PYROXENES (Gr. *pur*, fire, and *zenos*, a stranger). A group of mineral species found mostly in basic igneous rocks.

RADIOLARIA (L. *radiolus*, a little rod). A group of simple animals belonging to the Protozoa, and usually having siliceous shells.

REGIME (French). The condition reached by a river when it neither wears away its bed nor deposits material on it.

RHYOLITE (Gr. *rhuo*, I flow, and *lithos*, stone). An altered liparite.

SCREE (from Anglo-Saxon *scrithan*, to go or creep). The same as Talus.

STRATUM (L., a layer). A layer or bed of rock.

SYENITE (from Syene, a locality on the Nile). The typical plutonic rock of the Sub-acid Group.

SYNCLINE (Gr. *syn*, together, and *klino*, I bend). A trough-like fold of stratified rock.

TALUS (L. *talus*, the heel). The collection of broken rocks at the foot of a cliff or steep slope.

TEPHRITE (Gr. *tephra*, ashes, and *lithos*, stone). A basic lava rich in soda.

ZIRCON (Arabic *zarkun*, vermilion). A mineral species found as small crystals in many igneous rocks. Large crystals are used as gems

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